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SUSCEPTIBILITY AND RESISTANCE TO CITRUS-CANKER OF THE WILD RELATIVES, CITRUS FRUITS, AND HYBRIDS OF THE GENUS CITRUS [1]

[PRELIMINARY PAPER]

By GEORGE L. PELTIER [2]

Plant Pathologist, Alabama Agricultural Experiment Station

COOPERATIVE INVESTIGATIONS BETWEEN THE OFFICE OF CROP PHYSIOLOGY AND BREEDING INVESTIGATIONS, BUREAU OF PLANT INDUSTRY, UNITED STATES DEPARTMENT OF AGRICULTURE, AND THE DEPARTMENT OF PLANT PATHOLOGY, ALABAMA AGRICULTURAL EXPERIMENT STATION

INTRODUCTION

While many observations (see Table I) have been made on the susceptibility and resistance to Citrus-canker (caused by *Pseudomonas citri* Hasse) of the more common commercial varieties and species of Citrus, no systematic comparison has, as yet, been attempted to determine the susceptibility and resistance to canker of the wild relatives, the more obscure species and varieties, and the hybrids of Citrus as a whole. Owing to the strict quarantine measures against Citrus-canker and the inability to get together a representative collection of plants because of the time and funds necessary, a comparison of this kind has been impossible. Fortunately, through the efforts of Mr. W. T. Swingle, we now have represented in this country one of the most complete collections of Citrus plants and their relatives to be found in the world.

Through the cooperation of Mr. Swingle, the writer has been able to obtain plants from this collection, representing a large part of the family Rutaceae, to which the genus Citrus belongs. Plants have been placed for this study in the greenhouses at Auburn, Ala., and in the isolation field in the vicinity of Loxley, Ala.

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[2] The writer gratefully acknowledges his indebtedness to the following personnel of the Bureau of Plant Industry: Dr. K. F. Kellerman, Associate Chief, and Mr. W. T. Swingle, Physiologist in Charge, Crop Physiology and Breeding Investigations, for their cooperation and many helpful suggestions; Mr. D. C. Neal, Pathologist, for assistance rendered during the progress of the work; Mr. T. Ralph Robinson, Physiologist, Office of Crop Physiology, for his aid in the preparation of the manuscript; and Miss Wead, of the same office, for the preparation of the table and bibliography.

The results obtained from two sets of inoculation experiments in the greenhouse for the past five months have been of such a nature that their publication at this time is deemed advisable. It must be kept in mind that the results here reported are only of a relative nature, and in no case must they be considered absolute. This is especially true of those plants which are reported resistant. Of course, in the further search for varieties which are resistant to canker, the plants which showed marked susceptibility in the greenhouse experiments will be discarded.

EXPERIMENTAL METHODS

ORGANISM USED.—The organism (*Pseudomonas citri* Hasse) used in the inoculation experiments was isolated by Mr. D. C. Neal, by the ordinary dilution methods directly from soil taken under an infected grapefruit (*Citrus grandis*) near Fairhope, Ala., on July 20, 1917. Preliminary inoculations with this strain on grapefruit and Satsuma orange (*Citrus nobilis* var. *unshiu*) in the greenhouse proved that it was exceedingly virulent.

TYPE OF PLANTS USED.—Practically all of the plants used in the inoculation experiments were grown either from seeds or cuttings in the greenhouses at Washington, D. C. A few plants were included which had been budded on *Poncirus trifoliata* Raf., obtained from nurseries in Alabama. The size of the plants varied from 6 inches to 4 feet in height, and from those having a single stem to the large plants which had been cut back, with numerous shoots. The first lot of plants was received from Washington, D. C., on July 21, 1917, while the second shipment arrived on October 1, 1917. The plants were either cut back or were in a dormant condition when received; but by the time the first inoculation experiment was started, the majority were in excellent shape for infection. In discussing the results of the experiments the Crop Physiology and Breeding Investigations' (CPB) numbers used by Mr. Swingle are given so that the origin of the plants can be traced at any time by consulting his records.

METHOD OF INOCULATION.—As the plants varied in height, three sizes of inoculation cases were used. Care was taken in mixing the plants, so that all types were represented in each case. Just before setting the plants in the cases six punctures were made with a sterile needle on a mature leaf and an old leaf of each plant. The maturity of a leaf was judged by the size, condition, and to some extent by the number, size and pore length of the stomata. In a preliminary study it was possible to distinguish the different ages of the leaves by the methods used by Pool and McKay (*16*)[1] in their study of the species of Cercospora on beet. The results of the inoculation experiments were such that, unless stated in the discussion, no mention will be made of the infections occurring at the punctures.

[1] Reference is made by number (italic) to "Literature cited," p. 356-357.

At the time of the first inoculation, August 27, 1917, the plants in the two large cases were thoroughly sprayed with two 48-hour-old (100 cc.) cultures of *P. citri* in beef bouillon. A similar (100 cc.) culture was used for the smaller case. On September 12 the plants were again sprayed with half the amount of solution used above. The plants were removed on October 13 to a large screened case. The same day a second lot of plants were set in the cases and inoculated. These plants were again sprayed with 48-hour-old cultures of *P. citri* in beef bouillon on October 23 and November 1. The plants remained in the cases until January 13, when they were removed to the screened case where they are at the present time. Thus, the plants in Experiments I and II have been exposed to the Citrus-canker organism for a period of six months (February 27) and five months (February 12), respectively.

CONDITIONS GOVERNING INOCULATIONS.—During the course of the experiments a relatively high temperature has been maintained. On one or two nights during the cold weather the temperature dropped to 40° F., but the night temperatures averaged 60° and higher. During the day a temperature of approximately 90° and higher has prevailed the greater part of the time. Occasionally it dropped to 70° and at other times was nearer 95°. However, with these variations, a temperature has been maintained which, with other factors eliminated, made possible a maximum amount of infection.

Practically a 100 per cent humidity was kept in the cases. About once a week the plants were given a thorough spraying with a strong water pressure, a measure that would assist in distributing the canker organism. After the plants were transferred to the screened cage, they were sprayed on an average of twice a week. This spraying was carried out early in the morning, so as to produce a condition somewhat similar to a heavy dew. So far as humidity was concerned, then, infection was possible practically all of the time. The facts that numerous spots developed and that leaves were defoliated by canker in the screened case during the winter proved that these conditions were ideal for infection.

Another point that might be mentioned is that the plants were exposed to rather strong sunlight, as only a very light shade was used on the glass of the house.

Early in the work it was found that, even though ideal conditions of temperature and humidity were supplied for infection, few or no canker spots developed if the plant was not in good growing condition. The largest number of spots naturally occurred on mature leaves which were still tender and of a light-green color. Few spots appeared on the young leaves, while spots developed on the old foliage of the more susceptible plants only. Thus, it is a hard matter to fix any definite scale of susceptibility or resistance for a comparison of the different plants, especially when so many types are represented. However, by comparing

the character of growth of the plants and the number and type of spots produced, one can make a comparison in a relative way.

It must be borne in mind, then, that all the inoculations were carried out in the greenhouse under conditions of high humidity and temperature. The condition of the plant also played an important rôle in its susceptibility and resistance to Citrus-canker. By a close study of the plants and by the number and type of the spots it is possible to determine in a relative way and make comparisons of the susceptibility and resistance of the plants used in these experiments. Unless otherwise stated, plants have been in good growing condition suitable in each case for developing infection.

SUSCEPTIBILITY OF WILD RELATIVES OF THE GENUS CITRUS

RUTACEOUS PLANTS NOT CLOSELY RELATED TO THE GENUS CITRUS

Xanthoxylum Bungei[1] Planch. (CPB 11180, seedling), II.[2]

A spreading, deciduous shrub or small tree native of North or Central China.

The plant (12 inches in height) was in fair shape during the early part of the experiment, as the new growth was young and in fine shape for infection. While blister-like swellings developed soon after inoculation in the case, no canker spots were produced. Isolation cultures made from these swellings yielded negative results.

Casimiroa edulis Lav. and Lex. White sapote (CPB 7923, seedling), II.

A large tree native of Mexico.

No spots of any description have appeared on the foliage, although it has been completely surrounded by badly infected plants.

Glycosmis pentaphylla DC. (CPB 2905, seedling), II.

A small shrub common to the Orient.

No canker spots have appeared on any of the leaves.

Claucena Lansium Skeels. Wampi (CPB 7936, seedling), II.

A low-spreading tree native to South China.

No spots of any description have developed on the leaves.

Chalcas exotica Millsp. (*Murreaa exotica* L.). Orange jessamine (CPB 7975A, seedlings), I. II.

A small tree commonly grown in greenhouses for ornamental purposes.

No canker spots have appeared on either plant.

RUTACEOUS PLANTS BELONGING TO TRIBE CITREAE

Subtribe Aeglinae (Hardshell Fruits)

Aegle Marmelos Correa. Bael fruit (CPB 7983, seedlings), I, II.

A tree native to North India, but widely cultivated in India and surrounding countries.

No canker has developed on the foliage.

Aeglopsis Chevalieri Swingle (CPB 7633 and 7772, seedling and cuttings), II and I, II.

A large shrub growing near the coast in tropical western Africa.

No spots of any description have appeared on the leaves.

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[1] The nomenclature used by Mr. W. T. Swingle and others in Bailey's Standard Cyclopedia of Horticulture is followed in the article. It is suggested that this work be consulted frequently in this connection so that the nomenclature and synonymy of the plants used in the experiments will be clearly understood.

[2] Roman numeral refers to the number of the inoculation experiment.

Chaetospermum glutinosa (Merrill) Swingle (*Aegle glutinosa*, Merrill). Tabog (CPB 7799, seedlings), I, II.

A small spiny tree, native to the Island of Luzon, P. I., of promise as a useful stock for Citrus.

While several oily swellings have appeared on the young leaves, no definite canker spots have occurred. Isolations made from the suspicious spots yielded negative results.

SUBTRIBE FERONINAE (HARDSHELL FRUITS)

Feronia Limonia (Corr.) Swingle (*F. elephantum* Corr.). Wood-apple (CPB 2763, seedlings), I, II.

A small spiny tree, native to India, Ceylon, and Indo-China.

The leaves have remained free from canker spots.

Feroniella lucida Swingle. Kavista Batu (CPB 7882, seedlings), I, II

A small spiny tree, native to Java, somewhat resembling *Feronia Limonia*.

No spots have appeared on the leaves.

SUBTRIBE LAVANGINAE

Hesperethusa crenulata Roem. Naibel. (CPB 2759, seedling), II.

A slender tree native to the hills of India, Burma, and Indo-China.

No canker spots have developed on any of the leaves, although small spots caused by a fungus have been numerous.

Triphasia trifolia P. Wilson. Lime berry (CPB 2689A and 7780, seedlings), I, II, and II.

A small tree widely cultivated in tropical and subtropical regions as an ornamental.

These plants (10 to 18 inches) did not thrive well in the inoculation cases, and the lower leaves turned yellow and fell rapidly. However, new growth was produced quickly, so that young leaves were present at all times. No spots of any nature have developed on the leaves.

Severinia buxifolia Ten. (CPB 2760, cuttings), I, II.

A dwarf tree native to South China, introduced into Europe and recently into America.

The plants (8 to 12 inches), like *Triphasia trifolia*, did not thrive well in the cases, and defoliation was severe. However, new growth was present, and in good condition for infection. No spots of any kind have appeared on the foliage.

SUBTRIBE CITRINAE

NONEDIBLE FRUITS HAVING SESSILE PULP VESICLES WITH BROAD BASES[1]

Citropsis Schweinfurthii Swingle and M. Kellerman. African cherry orange (CPB 11260, seedling), II.

A small spiny tree native to Central Africa.

No spots of any kind have appeared on the leaves.

Atalantia citrioides Pierre. (CPB 7534, cuttings), I, II (2 plants).

A small spiny tree native to Indo-China.

These plants (6 to 10 inches) did not thrive in the greenhouse, the leaves defoliated rapidly, and in January all but one plant was discarded. However, new growth took place during the experiments, so that infection was possible. No canker spots appeared.

[1] In a recent conference with Mr. Swingle he stated that the subtribe Citrinae might well be split up into two groups to include plants having (*a*) nonedible fruits having sessile pulp vesicles with broad bases, and (*b*) edible fruits with stalked pulp vesicles.

EDIBLE FRUITS WITH STALKED PULP VESICLES

Poncirus trifoliata (L.) Raf. (*Citrus trifoliata* L.). Trifoliate orange (seedling, Alabama), II.

The trifoliate orange, which is a small spiny deciduous tree native to North China, is used to the exclusion of all other plants as a stock for *Citrus* spp. in Alabama. Hedges and trees are also widely scattered through the State. It has been fairly well established that Citrus-canker was imported from Japan into Alabama, directly and indirectly, on trifoliate seedlings. In Alabama it ranks next to grapefruit in susceptibility to canker in the field. With the gradual elimination of grapefruit growing from Alabama, the trifoliate orange becomes of major importance in the eradication of canker in that State.

Unfortunately the plant included in the experiment remained dormant, and no new growth developed. However, a few infections have occurred on the old leaves. Owing to the lack of good infections for comparison, the type of spots produced will be omitted.

Eremocitrus glauca (Lindl.) Swingle. (*Triphasia glauca* Lindl.; *Atalantia glauca* Benth.) Australian desert kumquat (CPB 7239, seedling), I, II.

A small hardy drougth-resistant tree with very small leaves and slender spiny twigs, found in Australia. It is one of the most interesting plants in Mr. Swingle's collection.

Typical Citrus-canker spots appeared on the leaves, twigs, and thorns six weeks after inoculation in Experiment I and in three months in Experiment II. Infection apparently takes place only on the upper surface of the leaves. The spots are minute, 0.3–0.5 mm. in diameter, circular, light brown at first, becoming darker with age, raised, compact, with little or no cork. The spots do not push through the leaf. Only an indistinct oily outline is present with a rather wide yellow zone. The spots increase very slowly with age, but one spot is sufficient to cause defoliation. The spots on the thorns and twigs are identical with those on the leaves.

It is extremely difficult to judge its relative susceptibility, owing to the peculiar nature of the plant. However, Citrus-canker attacks the leaves, thorns, and twigs, and as one spot is sufficient to cause defoliation, it is apparently quite susceptible.

Fortunella margarita (Lour.) Swingle. (*Citrus margarita* Lour.). Oval kumquat (CPB 7597, seedling), II.

The oval kumquat is quite widely grown in the Gulf coast section of Alabama. In the field kumquats have been reported as susceptible in only one or two cases, so that they are considered to be resistant by most growers.

As the plant (33 inches) was cut back for shipment, the young shoots were in excellent shape for infection at the time of inoculation. Citrus-canker spots appeared two months after inoculation and increased quite rapidly in numbers, so that practically all the mature leaves had one or more spots.

These results are quite interesting, in view of the resistance of kumquats shown in the field. The fact that maximum infection was obtained under the conditions governing the inoculations is very well shown here.

The spots are not numerous, averaging slightly above 1 mm. in diameter, chocolate-brown in color, slightly raised, compact, and occasionally corky. Spots rarely penetrate the upper surface, sometimes showing as a small, flat, oily, light-brown blister. The oily outline is very distinct, and no yellow zone is present. Citrus-canker does not cause defoliation, nor any apparent injury to the leaves. Only leaf infections have developed. Judging from the size and character of the spots, the plant is fairly resistant to canker, and it is not severe enough to cause any injury to the trees.

Fortunella crassifolia Swingle. Meiwa kumquat (CPB 11047, seedlings), I, II.

A little-known kumquat recently introduced into the United States by Japanese nurserymen.

In contrast to the fine condition of the oval kumquat, the plants (20 inches) are seedlings with a single shoot and have remained in a more or less dormant condition throughout the experiments. Consequently no canker has developed on these plants, even at the punctures, showing that the condition of the plants is of extreme importance in inoculation work of this character, and that unless all of the plants are in vigorous growing condition, no comparisons can be made. Inoculations with this kumquat will be repeated with more vigorous plants, and no doubt they will be found susceptible to some extent.

Fortunella Hindsii (Oliver) Swingle (*Sclerostylis Hindsii* Champ.; *Atalantia Hindsii* Oliver). Hongkong wild kumquat (CPB 11046C, seedlings), I, II.

This kumquat, which differs in some respects from the others, grows wild on the dry hills about Hongkong. Unfortunately no clear and concise test was made of this species, because the plants (12 inches) have remained in a more or less dormant condition throughout the experiments. Citrus-canker spots appeared early on the plant in the first experiment at four punctures on an old, tough leaf. Judging from the size and character of these spots, it will prove more susceptible than the oval kumquat. Inoculations will be repeated on more vigorous plants.

Microcitrus australasica (Muell.) Swingle (*Citrus australasica* Muell.). Finger lime (CPB 7600 and 7600B, cuttings and seedling), I, II, and II.

A small tree, native to the mountains of New South Wales and Queensland, Australia.

No spots of any kind have developed on the leaves.

Microcitrus australasica var. **sanguinea** Swingle (CPB 7775B, cutting), II.

A blood red variety of *M. australasica*.

No spots have appeared on the leaves.

Microcitrus Garrowayi (Bail.) Swingle (*Citrus Garrowayi* Bail.). Garroway's finger lime (CPB 11008, cuttings), I, II.

A plant similar to *M. australasica* and native to the same region.

A few oily swellings have developed which yielded negative results on making isolations.

Microcitrus australis (Planch.) Swingle (*Citrus australis* Planch.). Dooja (CPB 7307 and 7427, cutting and seedling), I, II.

An Australian lime, much more vigorous than the others, growing in the subtropical coastal forests of New South Wales and Queensland. The first plant (8 inches) developed very slowly and did not produce much new foliage. The second plant (32 inches), however, developed a large amount of new growth and has been in splendid condition for infection. Numerous Citrus-canker spots appeared on the leaves, twigs, and thorns of this plant one month after inoculation. Since that time canker has caused rapid defoliation of the plant, so that 50 per cent of the leaves have fallen. The plant is very susceptible. No doubt the other species of Microcitrus will prove susceptible to some extent when the right conditions are met with.

The spots (Pl. 53, G.) produced are numerous, small, occasionally 1 mm. in diameter, of a chocolate-brown color, raised, corky, and pushing through to the upper surface. Little or no oily outline is visible, while the yellow zone is wide and very distinct. Defoliation was rapid, and twig and thorn infection severe. The plant is quite susceptible, ranking slightly below *Poncirus trifoliata*.

From the results, up to March 1, 1918, of the inoculations in the greenhouse on the wild relatives of citrus, it appears that Citrus-canker is apparently limited to those plants having edible fruits with stalked

vesicles of the subtribe Citrinae. The susceptibility of the plants closely related to the genus Citrus is in the following order: *Poncirus trifoliata*, *Microcitrus australis*, *Eremocitrus glauca*, *Fortunella Hindsii*, and *Fortunella margarita*.

No doubt some of the other species and varieties of the wild relatives will prove susceptible when other tests are made with vigorous growing plants.

SUSCEPTIBILITY OF CITRUS FRUITS

Citrus Hystrix DC. (CPB 7872, seedlings), I, II.

A little-known group of plants found in the Philippine Islands, where they are sometimes used as a stock for Citrus spp. A characteristic plant with very large petioles.

Neither plant (20 inches) was in very good condition for infection; consequently Citrus-canker did not develop rapidly. However, spots appeared on the leaves and twigs, and some defoliation has resulted. Plants are not quite as susceptible as grapefruit.

The spots (Pl. 52, C) resemble those described on grapefruit in their general characters.

Citrus Hystrix Wester. "Cabayao" (CPB 7831, seedling), II.

A plant similar to the above. Owing to better condition of the plant (20 inches), citrus-canker has been much more severe. Apparently it is as susceptible as grapefruit. Infections are found on the leaves and twigs and some defoliation has resulted. The spots are identical with those on *C. Hystrix* 7872 (Pl. 52, C.).

Citrus Medica L. Citron of commerce (CPB 7768, cuttings), I, II.

Both plants (20 inches) pushed out an abundance of new growth while in the cases. Citrus-canker spots appeared on the leaves two weeks after the first inoculation. At the present time the spots are fairly well distributed over the leaves, and new infections are developing weekly. Canker is confined to the leaves and has not caused any defoliation.

The spots (Pl. 50, A) are fairly well distributed over the leaf, small, occasionally measuring over a millimeter in diameter, with no apparent increase in size. They are light brown at first, becoming darker with age. The spots are raised and somewhat corky, breaking through the upper surface and appearing flat and compact. The oily outline is distinct and is present only around unbroken spots, while the yellow zone is quite wide.

Several other species of *C. Medica* gave positive results, the order of susceptibility being as follows: "Etrog" citron 11178, "Sidro" citron 7816, citron of commerce 7768, "Nana" citron 11281, citron 7836, "Odorata" citron 11294.

The same type of spot (Pl. 50, A) was found on all the plants, and in some cases where they were extremely numerous on a leaf caused defoliation. However, owing to the small size of the spots, no injury resulted when they were scattered over the leaf. The number of spots per leaf does not influence their size. This point is important in judging the susceptibility of the citrons.

Citrus sp. Small lemon (CPB 7833, seedling), II.

An introduction from the Philippines.

The new growth has been excellent and consequently in fine shape for infection. Citrus-canker appeared on the foliage early in the experiment and has spread very rapidly to all the leaves, causing considerable defoliation. Numerous spots are present on the upper surface of the leaves. Twig infections are rather severe. The plant is extremely susceptible.

The spots are very numerous, small to large, light brown, raised, compact, spreading, and corky. The spots break through to the upper surface and are raised, corky, and spreading. Oily outline is distinct, while the width of the yellow zone varies. Very much like spots (Pl. 50, B) on grapefruit in general character. Spots different from those on citron in a number of particulars, but especially in size and appearance on upper surface.

Citrus sp. Sweet lemon (CPB 1158, seedlings), I, II.

An introduction from Jaffa, Palestine.

Both plants (16 inches) have been in fine condition for infection. Citrus-canker appeared on the foliage shortly after the first inoculation and has spread rapidly. Infections occurred on both surfaces of the leaves, and on the twigs and the thorns. It has caused defoliation of the more badly infected leaves. The plants are extremely susceptible.

The spots (Pl. 53, H) are very numerous, small to medium size, light-brown to brown, raised, more or less compact, with some cork. The spots cause a dead depressed area on the upper surface, but do not break through. An oily outline is present, while the yellow zone is indistinct, except when the spots coalesce. The spots are like those on citron except in size.

Citrus sp. "Davao lemon" (CPB 7837, seedling), II.

An introduction from the Philippines.

The leaves of this plant (18 inches) have the texture of citron leaves, with the shape and petiole of lemon leaves. The new growth has been fine, and in excellent shape for infection. Citrus-canker appeared early in the experiment and has spread rather rapidly over the foliage, so that infection has been rather heavy. The plant is susceptible to a marked degree, although not so much as some of the other lemons. The character of the spots (Pl. 53, I) is like that on the citron except in size. This may be expected, owing to the citron-like texture of the leaf.

Citrus sp. Limon real 18 (CPB 7819, seedling), II.

The leaves of this plant (18 inches) have the texture of citron leaves, with the shape and petiole of lemon leaves. The new growth has been fine, and was in excellent shape for infection. Citrus-canker appeared early in the experiment, and has spread rather rapidly over the foliage, so that infection has been rather heavy. The plant is susceptible to a marked degree, although not so much as some of the other lemons.

The character of the spots (Pl. 50, D) are like those on the citron. This may be expected, owing to the citron-like texture of the leaf.

Citrus sp.(?). Ichang lemon (CPB 11291, seedling), II.

Introduction from Hankow, China.

Judging from the character of the leaves, this is not a true lemon, but possibly is a hybrid. The leaves are dark green, smooth, pointed at the apex, with a large winged petiole. Occasionally a small leaflet arises from the point of union between the leaf and petiole. More or less pummelo-like in character.

The plant (10 inches) has been in good shape for infection. Citrus-canker appeared early in the experiment and spread rather rapidly. This plant is about as susceptible as grapefruit.

The spots are not numerous, but large, light brown, slightly raised, spreading, with cork present, breaking through the upper surface, forming a flat, spreading, compact spot. The oily outline is quite distinct, and the yellow zone is conspicuous. The spots are typical of those found on grapefruit leaves (Pl. 50, B).

Citrus aurantifolia (Auct.) Swingle (*C. limetta* Auct., not Risso.). Sour lime (CPB 7338, seedling), II.

The plant (18 inches) has been in fairly good shape for infection. Canker spots developed shortly after inoculation and have spread rapidly. At the present time the majority of the mature leaves are infected. While no defoliation has taken place, the plant is susceptible to a large degree.

The spots (Pl. 51, C) are numerous, small to medium size, rather dark brown, slightly raised, flattened on top, with some cork present. They break through the upper surface, forming either a small slightly raised spot or a depressed dead area. The oily outline is quite distinct. No yellow zone is present. The type of spot is rather characteristic and can not be compared directly to any of the other types discussed.

Citrus grandis (L.) Osbeck (*C. decumana* L.). Grapefruit (CPB 11170, seedlings), I, II.

The plants (12 inches) have been in only fair condition, so that infection was not as heavy as might be expected of grapefruit. However, spots have developed on the leaves and twigs. Some defoliation has taken place. The plants are extremely susceptible.

The spots (Pl. 50, B) are few per leaf, large (5–6 mm. in diameter), brown, raised, spreading, corky, breaking through the leaf and forming the same type of spot. The oily outline is very distinct and the yellow zone wide. A few spots on a leaf are sufficient to cause defoliation. The size of the spot is influenced somewhat by the number to the leaf.

Citrus grandis (L.) Osbeck (*C. decumana* L.). Grapefruit (budded on *Poncirus trifoliata*, Alabama).

As the plant (13 inches) was in poor shape for infection during the course of the experiment, only a few spots developed on the old leaves. However, they are typical of those on the preceding plants except in size. The degree of susceptibility of a plant can be judged somewhat by the number of spots occurring on the old tough foliage, as in the case of this plant.

Citrus grandis (L.) Osbeck (*Citrus decumana* L.). Pummelo (CPB 7834, seedling), II.

The leaf characters of this plant are very similar to grapefruit. However, the shape of the leaf differs somewhat, and the petiole is more winged.

The plant (13 inches) has been in excellent shape for infection, owing to the rapid growth of the young foliage. Citrus-canker has developed on the leaves, also along the midrib on the upper surface, twigs, and thorns. The plant is extremely susceptible, more so than grapefruit. Defoliation of the upper leaves by Citrus-canker has been rapid.

The spots (Pl. 51, B) are typical of those found on grapefruit in all details.

Citrus grandis (L.) Osbeck. Hirado Buntan (?). Pummelo. (CPB 7993, seedling), II.

A plant very similar to the preceding form, except that the petiole is slightly more winged.

As the plant (12 inches) made a rapid growth in the cases, Citrus-canker developed very early in the experiment. It is extremely susceptible, and defoliation by canker has been rapid. Apparently it is about as susceptible as pummelo 7834.

The type of spots (Pl. 50, B) produced is similar in all respects to those on grapefruit.

The identity of this pummelo as Hirado Buntan is in doubt as the plant numbers became mixed in transferring them from the greenhouses in Washington. In Japan the Hirado Buntan was noted by Mr. Swingle in 1915 as being decidedly canker-resistant.

Citrus nobilis Lour. "Naranjita"? (CPB 7830, seedling), II.

The leaf characters of this plant resemble those of the Satsuma.

Although the plant (14 inches) has ben in fairly good condition for infection, only one small Citrus-canker spot has developed. It will be tested again, as it gives some promise of being resistant to canker.

Citrus nobilis var. **unshiu** Swingle. Satsuma (budded on *Poncirus trifoliata*, Alabama), II.

Although the plant (36 inches) has not been in good condition for infection, Citrus-canker has developed on a number of leaves. However, infection was not severe and caused no defoliation or apparent injury to the leaves.

The spots (Pl. 52, E) are few in number, small, brown, raised, compact, with no cork present, breaking through to form a blister-like spot. The oily outline is distinct, with only a faint yellow zone. Resembles infections on *Fortunella margarita*.

Citrus mitis Blanco. Calamondin orange (CPB 11265 and 44305, seedlings), I, II, and II.

A hardy tree, native to the Philippine Islands, and commonly grown in Hawaii. Some years ago distributed by nurserymen in this country under the name "tokumquat."

The first two plants tested (15 inches) remained in a poor condition throughout the experiment, so that little or no Citrus-canker developed. However, the third plant (20 inches) has been in good condition for infection. Canker has been rather severe on the plant and has caused some defoliation of the leaves. Spots are present on the upper surface of the leaves. Not as susceptible as grapefruit.

The spots (Pl. 52, A) are many, small to medium size, light brown, and raised, compact, corky, forming a depressed dead area on the upper surface. Oily outline is indistinct, while yellow zone is scarcely visible.

Citrus sp. "Naranja," native orange (CPB 7929, seedling), II.

A recent importation from Porto Rico. Leaf characters very much like a grapefruit.

The plant (15 inches) has been in fairly good shape for infection and Citrus-canker has been sevete. About as susceptible as grapefruit.

The spots (Pl. 51, A) are fairly numerous, medium to large, light brown, raised spreading, corky, breaking through the upper surface to form a depressed dead area or a raised spreading spot. The oily outline is quite distinct, while the yellow zone is almost absent.

Citrus sp. Kansu orange (CPB 11242, seedling), II.

An interesting plant collected by Mr. Frank N. Meyer in North China and not yet described. Apparently very hardy.

The plant (20 inches) thrived very well in the greenhouse, and new growth has been abundant. While Citrus-canker has developed on most of the mature leaves, it is causing no injury to the foliage whatever, and it gives promise of showing considerable resistance to canker in this respect.

The spots (Pl. 52, B) are many, extremely small (0.3 mm.), and not increasing in size, dark brown, raised, compact, not corky, not breaking through to upper surface. In fact, Citrus-canker can not be detected from a glance at the upper surface of the leaves. The oily outline is absent, and there is not the faintest trace of a yellow zone.

Three species of Citrus known in the Philippines as "colo-colo" (CPB 7820), "talamisan" (Pl. 51, D) (CPB 7827), and "tegi-tegi" (CPB 7818) proved susceptible, resembling in type of infection, respectively, sweet lemon, grapefruit, and citron.

Citrus excelsa Wester (CPB 11280, seedling), II.

A citron-like plant recently introduced from the Orient.

Owing to the poor condition of the plant (10 inches), little Citrus-canker has developed. However, what few spots are present on the leaves resemble those on the citrons.

These results obtained show that all of the Citrus fruits are more or less susceptible to Citrus-canker. While it is true that the plants included in the inoculation experiments represent only a small portion of the species and varieties found in this group, apparently the only plants which show any marked resistance to Citrus-canker are those included under *Citrus nobilis* and the Kansu orange. *Citrus mitis*, which has been reported to be resistant to canker in the Philippines (*26*), can hardly be classed with the promising resistant forms under greenhouse conditions. However, tests with this species will be repeated both in the greenhouse and in the field.

The type of spots produced on the various plants are striking, and in many cases the plants can be classed from a botanical standpoint, and relationships traced by the character of the spot. The susceptibility of the plants can also be arranged by the number and type of the spots per leaf. The spots vary from 6 mm. in diameter on grapefruit (Pl. 50, B) to 0.3 mm. on the Kansu orange (Pl. 52, B). While the size of the spot is influenced to some extent by the number of spots on the leaf surface, apparently those plants on which the small spots are found are not as susceptible as those with the large spots, as in the case of grape fruit.

SUSCEPTIBILITY OF CITRUS HYBRIDS

Faustrime (*C. aurantifolia*, West Indian lime, × *Microcitrus australasica*) (CPB 49819 and 49823, cuttings), II.

These hybrids retain to a large extent the characteristics of species of Microcitrus.

The plants (12 to 18 inches) have not been in good shape for infection during the experiment. Not much new growth has developed, so that they have not had a good test.

Up to March 1, 1918, only two small spots (Pl. 53, F) have developed, one at a puncture and the second on a small leaf. *Microcitrus australasica* has remained resistant, so that it is interesting to note that the hybrid is very slightly susceptible.

Faustrimon (*C. Limonia*, lemon, × *Microcitrus australasica*). (CPB 49824 and 49843, cuttings), II.

The plants (6 to 8 inches) are smaller and resemble very closely *Microcitrus australasica*. The growth of the foliage has been very slow so that they have been in only fair shape for infection.

No spots of any kind have developed on the leaves.

Citrange, Colman (*Poncirus trifoliata* × *C. sinensis*). (CPB 7896, seedlings), I, II.

The plants (18 inches) have been in only fair shape for infection. However, Citrus-canker appeared shortly after the first inoculation (15 days) and spread quite rapidly over the mature leaves. During the colder weather, when it was impossible to maintain a high temperature, the plants defoliated quite badly, so that few infections have occurred during the last two months. This was true of all the citranges.

The spots (Pl. 53, B) vary in numbers per leaf from one to many. They are small to large (2–3 mm) (Pl. 53 B, E), light to dark brown, raised, somewhat spreading, and corky, breaking through to the upper surface to form a slightly raised spreading spot. The oily outline is distinct, while the yellow zone varies in width. This description characterizes the spots on all the citranges. All are typical of those found on the *Poncirus trifoliata.*

With the exception of the Willits citranges, the following citranges tested showed approximately the same degree of susceptibility as the Colman: Cunningham (CPB 7665); Morton (CPB 771A (Pl. 50, E) and 761AC); Rusk (CPB 7956, 11030, and 44980); Rustic (CPB 7934A); Sanford (CPB 7963); Savage (CPB 7961); citranges (CPB1416 43480, and 43491).

Citrange, Willits (CPB 7897, seedlings), I, II.

These plants (14 inches) have been in fine shape throughout the experiments and have retained their foliage. The leaves have held their dark-green color. While Citrus-canker is fairly well distributed over the foliage, it is the only citrange that gives promise of showing any resistance to canker.

The citranges as a whole, with the possible exception of Willits, are equally susceptible to Citrus-canker, and no doubt under field conditions they will probably show about the same susceptibility as *Poncirus trifoliata.* This is to be expected since it is known that both parents of the citranges are quite susceptible to canker.

The character of the spots are similar on all the plants and resemble those produced on *Poncirus trifoliata.* As all the leaves of the hybrids are trifoliate and of the same texture as those of the trifoliate orange, naturally the same type of spot would occur.

Citrumelo (*C. grandis,* Bowen grapefruit, × *Poncirus trifoliata*). (CPB 4493, 4554, 4564, seedlings), I, II, I, II, and I.

The plants (9 to 16 inches) varied a great deal in their condition for infection. On the whole, considerable new growth developed, and as a consequence Citrus-canker appeared early in the experiments and spread rapidly to the young and mature leaves. Spots are present on the leaves, twigs, and thorns, and have caused considerable defoliation on one or two plants. Apparently as susceptible as either parent, grapefruit or trifoliate orange.

The spots (Pl. 53, A) are numerous, medium to large, light to dark brown, raised, spreading, and corky, breaking through to the upper surface to form a slightly raised, corky and spreading spot. The oily outline is distinct, and the yellow zone varies in width. The spots resemble to some extent those found on both parents, but are not typical of either.

Citradia (*Poncirus trifoliata* × *C. Aurantium,* sour orange). (CPB 50850, seedlings), I, II.

The plants (10 inches) have been in only fair shape for infection, although new growth developed once during the experiment. Citrus-canker appeared shortly after inoculation at the punctures but spread slowly to the healthy foliage. However, new infections were noted at each monthly reading. Apparently the plants are quite susceptible but not as much so as either parent. No doubt this hybrid will prove as susceptible to Citrus-canker as the parents when more vigorous plants are inoculated.

The spots are few, small to large, light to dark brown, slightly raised, compact, with little cork, breaking through the upper surface to form a compact spot. The oily outline is distinct, and the yellow zone varies in width. The spots are more or less typical of those found on *Poncirus trifoliata.*

Citrandarin (*C. nobilis*, King of Siam orange, × *Poncirus trifoliata*). (CPB 40210, 40303, 40315, seedlings), I, II.

The plants (7 to 15 inches) have been in fair shape during the experiments and some new growth has developed. Citrus-canker appeared at the punctures, but spread very slowly on the healthy leaves, so that only a few spots developed on each plant. This hybrid shows some resistance to canker and is about as resistant as the Satsuma orange.

The few spots (Pl. 53, D) present are rather typical of those found on *Poncirus trifoliata*. This is probably due to the leaf texture, which is about the same as that of the trifoliate orange.

Cicitrange (*Poncirus trifoliata* × Colman citrange, and *Poncirus trifoliata* × Sanford citrange). (CPB 48290, 48316A, seedlings), I, II and I, II.

Most of the plants (8–20 inches) have been in fine shape for infection. Citrus-canker appeared shortly after inoculation and spread rapidly to the new growth, where it was very severe, causing considerable defoliation. The spots are present on the leaves, twigs, and thorns. The plants are as susceptible as the trifoliate orange. It is interesting to note that the citranges used in the crosses are both very susceptible. The spots (Pl. 53, C) are typical of those found on the trifoliate orange.

Citrangequat (Willits citrange × *Fortunella margarita*). (CPB 48010, seedlings), I, II.

These interesting plants (12 inches) have made a very slow growth while in the cases, but new growth has been present practically all the time. Even though the plants were set under plants literally covered with Citrus-canker, they have remained resistant. This hybrid is the most promising of all the hybrids so far tested. Further inoculations both in the field and greenhouse will be carried out with a number of plants under different conditions to test out this resistance.

It might be pointed out in this connection that the Willits citrange, which shows more resistance than any of the other citranges, was used as one of the parents of this hybrid.

Citranguma (*C. nobilis* var. *unshiu*, Satsuma, × Morton citrange). (CPB 48055A, seedlings), I, II.

The plants (8 to 10 inches) have made a slow growth in the cases and have not been in good condition for infection. No Citrus-canker has developed on the plants, which are apparently resistant, although both parents are susceptible, especially the Morton citrange, which is highly so. Further tests will be made with this hybrid.

Limequat (*C. aurantifolia*, West Indian lime, × *Fortunella japonica*, Round kumquat). (CPB 48787A, 48787B, seedlings), I, II.

The plants (8 to 12 inches) have been in good shape for infection. This was especially true during the first two months, when Citrus-canker was rather severe on the leaves. Some defoliation resulted on one or two of the plants. The limequat is not as susceptible as the lime and not as resistant as the kumquat. Apparently where limes are used as a parent we can expect the hybrid to be susceptible, even though the other parent is fairly resistant. The susceptibility of the limequat should be contrasted with that of the citrangequat, where both parents are fairly resistant to canker. The spots (Pl. 53, J), while not as numerous per leaf area as those on the sour lime, are identical in character, except in size.

Limelo (*C. aurantifolia*, West Indian lime, × *C. grandis*, sour pummelo). (CPB 40502, 40526A, 40567B, seedlings), I, II, I, II.

The plants (8 to 19 inches) have been in fairly good shape for infection. Citrus-canker appeared very early in the experiment and spread rapidly. Spots are present on the leaves, petioles, twigs, and thorns, and some defoliation has resulted. The plants are apparently as susceptible, or more so, than either of the parents.

The spots (Pl. 52, D) are typical of those found on grapefruit.

Tangelo, Thornton (No. 2) (*C. nobilis* var. *deliciosa*, tangerine, × *C. grandis*, Florida grapefruit).[1] (CPB L715A, seedlings), I, II.

The plants (10 to 12 inches) have not been in the best of condition for infection, as growth was slow. Citrus-canker developed shortly after inoculation at the punctures, but did not spread rapidly to the young foliage, so that at the present time only a few of the leaves are infected. While the spots (Pl. 50, C) are typical of those on grapefruit, the hybrid gives some promise of being much more resistant to Citrus-canker than grapefruit.

Tangelo, Sampson. (CPB L789A, seedlings), I, II.

In many respects these plants (12 inches) were similar to the Thornton tangelo in their growth and behavior toward Citrus-canker.

Tangelo (CPB 1230, seedling), I.

The plants (14 inches) were in about the same condition for infection as the Thornton tangelo and appeared to be slightly more susceptible.

Tangelo (CPB 1257A, seedlings), I, II.

The plants were similar to tangelo 1230 in growth and susceptibility to canker. The spots, like those of the other tangelos, are typical of those described for grapefruit.

The results obtained with the hybrids are extremely interesting and instructive. When two susceptible plants are used in hybridizing the hybrid shows the same susceptibility as the parents. Good illustrations of this are the citranges and cicitranges, citrumelos, and limelos. However, when an extremely susceptible plant is crossed with a kumquat or a mandarin type of orange the hybrid retains to a large extent the resistance exhibited by the resistant parent, as illustrated by the behavior of the citrangequat, citranguma, citrandarin, and to a less extent by limequat and tangelos.

Unfortunately, no hybrids were included in the experiments where both parents show marked resistance.

In the further work of hybridizing for resistance to Citrus-canker the parents must be confined for the most part to those plants which show marked resistance to canker, especially in the genus Fortunella and *C. nobilis* with its many varieties.

DISCUSSION OF RESULTS

The factors necessary for the successful inoculation of the plants in these experiments, especially those which were somewhat resistant, are a high temperature, a relatively high humidity, and a vigorous and rapidly growing plant. Without the inclusion of the last factor only the more susceptible plants are infected. It is for this reason that the condition of the plants for infection has been given for each host discussed. When the plants were not in good shape for infection, few or no results were obtained. In such cases no relative comparisons of susceptibility or resistance could be made.

Under the conditions governing the inoculations, then, the maximum amount of infection possible was obtained. No doubt under ordinary

[1] This is not the true Thornton, but a sister variety, differing considerably though resulting from the same cross.

field conditions the more resistant plants would show almost absolute immunity, while the less susceptible plants would show more resistance to Citrus-canker. For example, a larger number of canker spots were produced on the oval kumquat in the greenhouse than has been reported on all the kumquats in the field since Citrus-canker was introduced into this country. Where the plants were in good condition for infection and remained resistant we may rest assured that they will be resistant under ordinary field conditions.

The fact that the plants were thoroughly mixed in the cases also helped to produce the greatest amount of infection. The writer found that the organisms isolated from susceptible plants grow very rapidly on potato plugs, while those from the more resistant plants develop slowly.

It is also very difficult to isolate the organism from the spots on the more resistant plants. No doubt, if all the resistant plants had been placed together in a case and inoculated, little or no canker would have developed and no reinfections would have been possible. Thus, by mixing the plants a higher percentage of hosts were infected and reinfected, owing to the spread of the more virulent organisms from the extremely susceptible plants.

The results may be influenced somewhat by the fact that small, rather young plants, mostly derived from seedlings, were used. Just how much the individual variations of the seedlings enters into the work will not be known until a number of inoculation experiments are carried out.

These plants are natives of various parts of the world and grow under diverse climatic and soil conditions. When brought together in an experiment of this nature, undoubtedly many of them are weakened, a condition that influences their behavior toward Citrus-canker.

It is indeed surprising to find from the inoculation experiments in the greenhouse that, so far Citrus-canker is apparently limited to those plants having edible fruits with stalked pulp vesicles, of the subtribe Citrinae, which includes only five genera. Of these, the genera Poncirus, Fortunella, and Microcitrus were formerly included in the genus Citrus, while Eremocitrus was first described as a Triphasia and then as Atalantia before being placed in a new genus by Mr. Swingle. It is interesting to note how closely susceptibility to Citrus-canker under greenhouse conditions ties up with the botanical classification of this group of plants as worked out by Mr. Swingle.

Jehle (*10*) (*11*) has reported *Xanthoxylum fagara* (L.) Sarg., *X. Clava hercules*, and *Chalcas exotica* Millsp. (*Murraea exotica*, L.) as being susceptible to Citrus-canker. His method of inoculation (needle pricks) and the fact that the plants were kept in a tightly screened cage (*8*) into which no direct sunlight could penetrate,[1] might make his results possible.

In the Philippines, Wester (*29*) has noted "what is apparently Citrus-canker" on *Chaetospermum glutinosa* (*Aegle glutinosa* Merrill). No

[1] Sides and top were double-screened on the outside with galvanized netting and on the inside with bronze screen of fine mesh, with a mote at the base.

isolations were made of this material, so that this observation has not yet been definitely substantiated.

These are the only Citrus relatives so far reported in the literature as being susceptable to Citrus-canker. It should be noted that the relatives mentioned in this connection are widely removed from Citrus, and if these are as susceptible as reported, we should surely anticipate results with the closely related plants as Citropsis and Atalantia, which belong to the same subtribe. Further inoculation in the greenhouse and field this season should go a long way in clearing up this situation.

Of the relatives *Poncirus trifoliata* is undoubtedly the most susceptible, followed by *Microcitrus australis*, while *Eremocitrus glauca*, *Fortunella Hindsii*, and *F. margarita* show some resistance to Citrus-canker. No doubt some of the plants which did not become infected will probably prove susceptible to some extent when good vigorous plants are used.

All of the species and varieties of true Citrus proved susceptible. The citrons, lemons, lime, grapefruits, pummelos, and similar plants are so susceptible that in the search for resistant forms they can be discarded, unless other pummelo strains possessing resistant qualities may be found. The plants belonging to the species *C. nobilis* and the Kansu orange are the only forms which exhibited any resistance to Citrus-canker. It is from this group and type of plants that resistant forms will be obtained in the future.

The results obtained with the hybrids have by far been the most interesting and instructive. Two of the hybrids, the citrangequat and citranguma, have thus far remained completely resistant, while the other hybrids having the mandarin type of orange for one parent have shown considerable resistance.

When susceptible plants like grapefruit and lime have been used in crossing, the resulting hybrid generally retains this susceptibility, while the resistant parents pass their resistance on to the hybrid. The most far-reaching results in the search for commercial resistant varieties will be obtained in the development and hybridizing of the forms which show some resistance to Citrus-canker.

The type and number of spots varies directly with the resistance exhibited by a plant. This offers a means of judging and comparing the relative susceptibility and resistance of the whole group. Apparently resistance is in part mechanical—for example, the texture of the leaf determines to a large extent the size and character of the spot. Leaf texture plays an important role in the resistance of the host plant to Citrus-canker and seems closely related to the rapidity with which the leaves mature. There is a considerable variation in the time required for the maturation of the leaves of the various Citrus plants. Thus, the leaves of the kumquat, which are rather thick and highly resistant, reaches maturity much sooner than the thin, extremely susceptible leaves of the grapefruit.

TABLE I.—*Relative susceptibility of different varieties of Citrus fruits to Citrus-canker, arranged according to dates of articles from which the table is compiled* [a]

[xxx, very susceptible; xx, susceptible; x, some resistance; o, decidedly resistant; oo, immune]

Species.	Stevens (*18*)	Wolf (*32*)	Stirling (*23*)	Stevens (*19*)	Edgerton (*4*)	Beattie (*1*)	Massey (*14*)	Stevens (*22*)
Grapefruit..........	xxx	xxx	xxx(1)	xxx	xxx	xxx	xxx	xxx
Orange:								
Sweet...........	oo	x	xx(6)	xx	xx	....	....	....
Navel...........	....	....	xx(5)	xx	....	....	....	x
Satsuma.........	x	xx	xx(7)	xx	xx	o	....	....
Mandarin........	....	....	xx(9)	....	....	....	....	....
Tangerine.......	....	....	oo(8)	xx	....	....	....	....
King............	....	....	xx(10)	....	....	....	....	....
Trifoliate........	xx	xx	xxx(2)	xxx	xxx	....	xxx	....
Lemon............	....	....	xx(11)	xx	....	....	....	....
Lime.............	....	....	xx (3, 4)	xx	....	....	....	....
Kumquat..........	....	oo	oo	oo	o	....	....	....

Species.	Berger (*2*)	Swingle (*24*)	Stevens (*20*)	Stevens (*21*)	Rorer (*17*)	Keller-man (*12*)	Wolf (*30*)	Dory-land (*3*)
Grapefruit..........	xxx(1)	....	xxx [b]	xxx	xxx(1)	xxx	xxx	xx
Orange:								
Sweet...........	xx(5)	....	xx	x	xx(5)	xxx	xx	xx
Naval...........	xx(4)	....	x	....	xx(4)	....	....	....
Satsuma.........	xx(6)	....	x	....	x(6)	xxx	x	....
Mandarin........	xx(8)	....	x	....	x(7)	....	x	....
Tangerine.......	xx(7)	....	x	....	....	....	x	o
King............	xx(9)	....	x	....	x(8)	....	....	o
Trifoliate........	xx(2)	....	xxx	xxx	xxx(2)	....	xxx	....
Lemon............	xx(10)	....	xx	....	x(9)	xxx	x	....
Lime.............	xx(3)	....	x	....	xx(3)	xxx	x	....
Kumquat..........	oo	xx	....	oo	....	....	x	....

Species.	Edgerton (*5*)	Wolf (*31*)	Mackie (*13*)	Jehle.		Newell (*15*)	Wester (*26-29*)	Fed. Hort. Bd. (*25*)
				(*6*)	(*7-9*)			
Grapefruit..........	xxx	xxx	xxx	xxx(1)	xxx(1)	xxx(1)	(c)	(d)
Orange:								
Sweet...........	xxx	x	....	x(5)	x(7)	x(1)	....	....
Navel...........	xxx	x	....	xx(4)	x	....	....	....
Satsuma.........	xx	o	....	x(6)	x	....	....	....
Mandarin........	xx	x	....	x(8)	x	....	....	....
Tangerine.......	xx	x	xx	x(7)	x(8)	x(8)	....	....
King............	....	x	....	x(9)	x(9)	x(9)	....	....
Trifoliate........	xxx	xxx	....	xxx(2)	xx(4)	xx(4)	....	....
Lemon............	....	x	xxx	x(10)	xxx(2)	xx(2)	....	....
Lime.............	....	x	o	xx(3)	xx(3)	xx(3)	....	....
Kumquat..........	o	x	....	o	o(11)	o(11)	....	....
Miscellaneous [e]	....	....	....	....	....	....	....	....

[a] Numbers in parentheses within columns indicate the relative order of susceptibility.

[b] Stevens (*20*); Inoculations on sweet orange, trifoliate, rough lemon, and grapefruit show about same degree of susceptibility to infection where growth and moisture conditions are the same.

[c] Wester (*26-29*): Mr. P. J. Wester has reported observations on the occurrence of canker under natural conditions at Lamao Experiment Station, near Manila, P. I. The collection of Citrus plants there includes about 1,000 separate numbers and embraces practically all the species of citrus being grown commercially in the United States, as well as many native and Asiatic forms, not commonly grown in this country. In addition to the recognized varieties (and some natural hybrids) observations were made on a large number of hybrids of the tangelo type furnished by the United States Department of Agriculture in connection with Crop Physiology and Breeding Investigations. The notes as to canker susceptibility showed in some cases results varying with the season of the year when observations were made and doubtless chance infection would have an influence as well. These observations are too detailed to report in this brief summary, and later examinations would probably make some changes necessary. It is significant, however, to note that there is a wide range of susceptibility under conditions favorable to the unrestricted spread of canker, some of the mandarin types of oranges being practically immune, while some of the tangelos showed marked resistance. Grapefruit and oranges of American origin are generally quite susceptible, while certain of the pomelos of Asiatic origin are reported as distinctly resistant.

[d] Federal Horticultural Board (*25*): Canker found on specimen of grapefruit and other Citrus species from Java and on five specimens from Japan.

[e] Miscellaneous varieties: Sour orange and tangelo are somewhat susceptible according to Jehle (*6-9*) and Newell (*15*). Mandarin limes are very resistant though not immune according to Jehle (*7-10*) and Newell (*15*). *C. pseudolimonum*, *C. l. aromatica*, *C. longispina*, *C. L. davaoensis*, and *C. webberii* are especially subject, *C. n. papillaris*, *C. mitis* and *C. w. montana* are practically immune according to Doryland (*3*). *C. micrantha* is quite susceptible according to Mackie (*13*).

From the results of the experiments it is a reasonable assumption that the virulence of the organism can be increased or decreased by a choice of hosts, just as the growth of the organism can be influenced on artificial media by giving it a favorable or unfavorable media on which to develop. By this means a very virulent strain can be built up by keeping it on grapefruit, while a virulent strain can be broken down by using kumquat as a host. There may be in nature different strains of canker organisms, and no doubt these do occur, but apparently these can be decreased or increased in virulence by the use of a susceptible or resistant plant, so that it all becomes a question of host relation.

SUMMARY

(1) Plants representing the more important wild relatives, species, varieties, and hybrids of Citrus were obtained from the United States Department of Agriculture and inoculated with *Pseudomonas citri* in the greenhouse to test their comparative susceptibility and resistance to Citrus-canker.

(2) The conditions under which the experiments were carried out were such that a maximum amount of infection was possible. The factors influencing infection were a high temperature, a relatively high humidity, and a rapid and vigorous growing plant.

(3) From the results of the greenhouse inoculations with young plants, Citrus-canker is apparently limited to those plants having edible fruits with stalked pulp vesicles of the subtribe Citrinae, which includes the genera Poncirus, Fortunella, Eremocitrus, Citrus, and Microcitrus.

(4) Susceptibility and resistance to Citrus-canker follow closely the botanical classification of this group as worked out in recent years by Mr. W. T. Swingle.

(5) Of the so-called relatives, the plants belonging to the genera Fortunella, Eremocitrus, and Microcitrus show some resistance to Citrus-canker, while Poncirus is extremely susceptible.

(6) All the species and varieties of Citrus tested are susceptible to canker. *Citrus nobilis* with its many varieties and types, the Kansu orange, and possibly *C. mitis*, exhibit enough resistance to warrant trials under Citrus-canker conditions in the field.

(7) Of the hybrids the citrangequat and citranguma have remained free from Citrus-canker in these tests, while the citrandarins, limequats, and tangelos show some resistance. The citranges, with the possible exception of Willits, cicitranges, citrumelos, and limelos are all extremely susceptible and can be discarded in the further search for resistant plants.

(8) The number, size, and character of spots on the leaves are of great assistance in judging the relative susceptibility and resistance of the plants.

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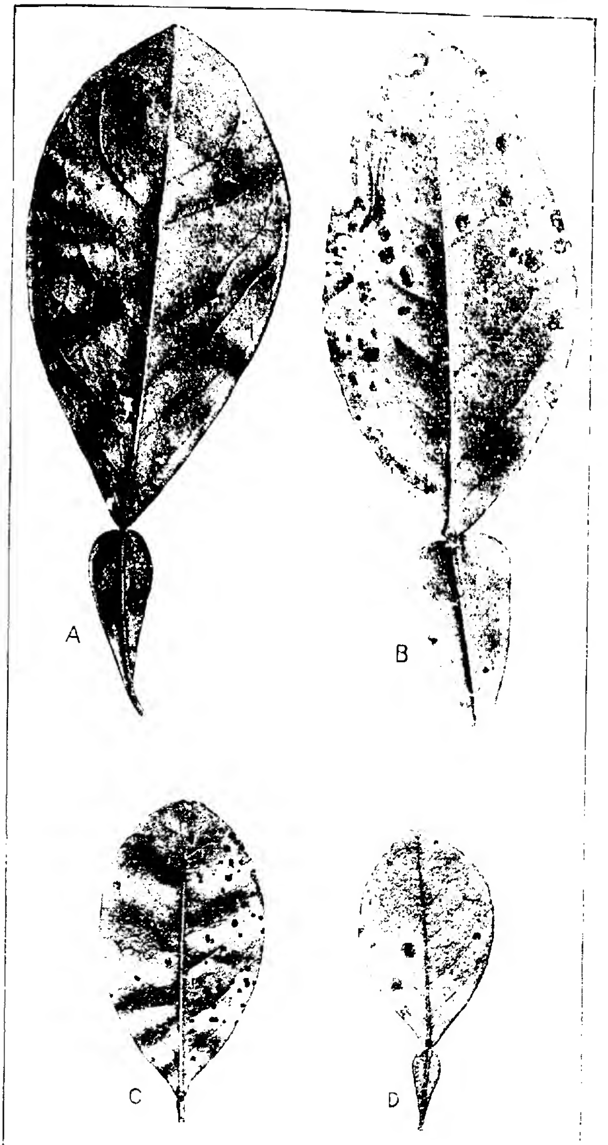
PLATE 50

Plates 50–53 illustrate the results of Citrus-canker inoculations in the greenhouse, showing the characteristic type and number of spots on the various plants. The spots are all representative of the particular host, approximately the same age and natural size.

A.—*Citrus Medica*, citron of commerce (CPB 7768);
B.—*Citrus grandis*, grapefruit (CPB 11170);
C.—Thornton tangelo (CPB L-715 A);
D.—*Citrus* sp., limon real 18 (CPB 7819).


A
B
C
D

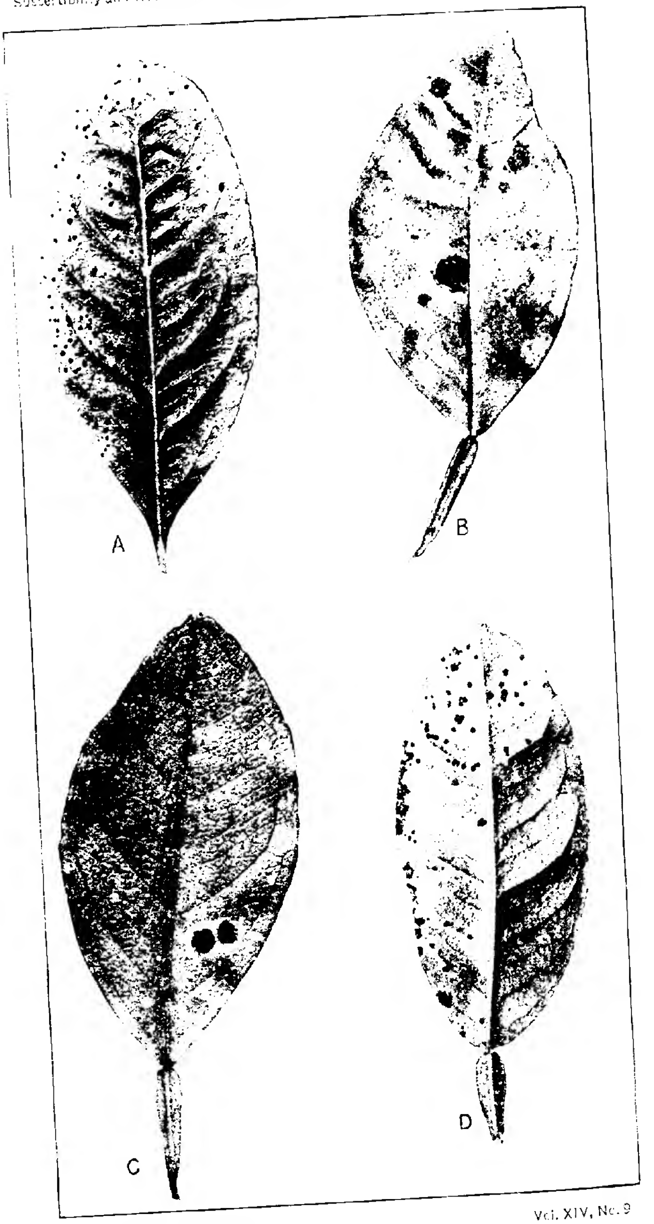

A
B
C
D

PLATE 51

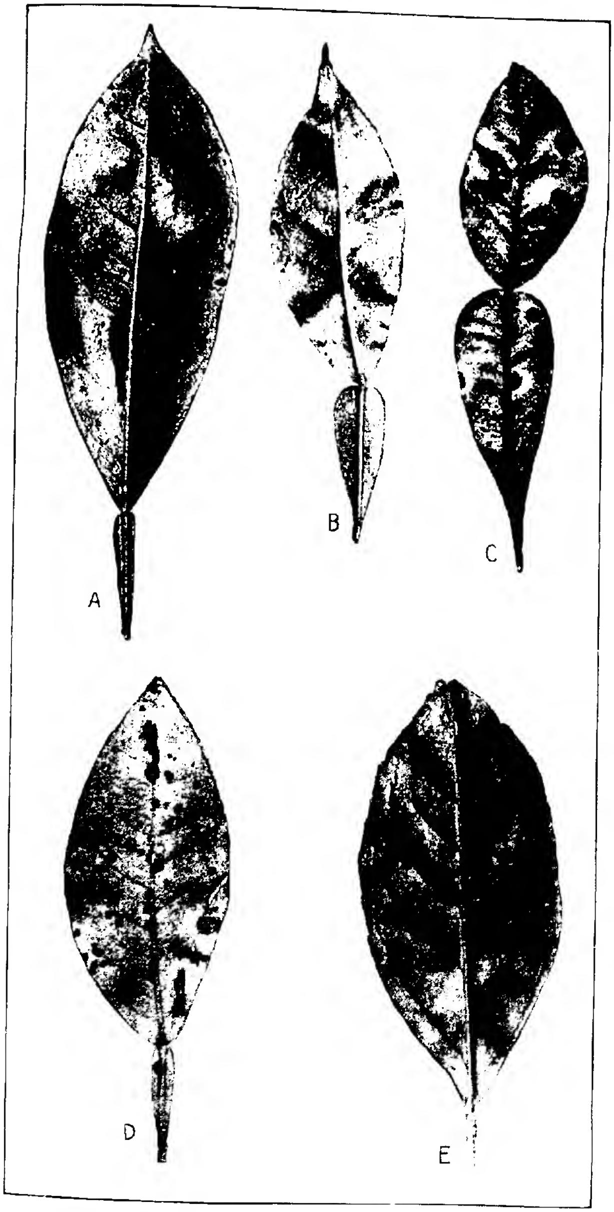
Results of Citrus-canker inoculations:

A.—*Citrus* sp., "naranja," native orange (CPB 7929);
B.—*Citrus grandis*, pummelo (CPB 7834);
C.—*Citrus aurantifolia*, sour lime (CPB 7338);
D.—*Citrus* sp., talamisan (CPB 7827).

PLATE 52

Results of Citrus-canker inoculations:

A.—*Citris mitis*, Calamondin orange (CPB 44305);
B.—*Citrus* sp., Kansu orange (CPB 11242);
C.—*Citrus Hystrix* (CPB 7872);
D.—Limelo (CPB 40567B);
E.—*Citrus nobilis* var. *unshiu*, Satsuma.


A
B
C
D
E

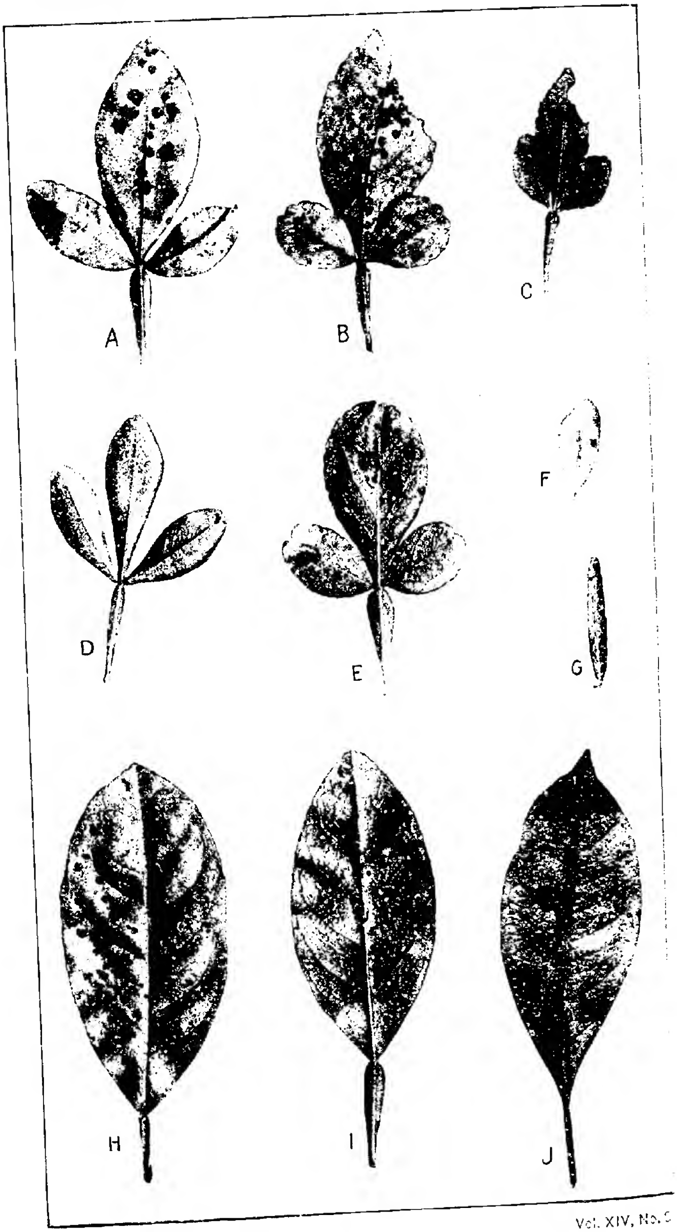

A
B
C
D
E
F
G
H
I
J

PLATE 53

Results of Citrus-canker inoculations:

A.—Citrumelo (CPB 4493);
B.—Colman citrange (CPB 7896);
C.—Cicitrange (CPB 48316A);
D.—Citrandarin (CPB 40210);
E.—Morton citrange (CPB 771A);
F.—Faustrime (CPB 49819);
G.—*Microcitrus australis* (CPB 7427);
H.—*Citrus* sp., sweet lemon (CPB 1158);
I.—*Citrus* sp., Davao lemon (CPB 7837);
J.—Limequat (CPB 48787B).

VARIATION AND CORRELATION IN WHEAT, WITH SPECIAL REFERENCE TO WEIGHT OF SEED PLANTED[1]

By A. C. Arny, *Head of Section of Farm Crops*, and R. J. Garber, *Assistant Plant Breeder, Minnesota Agricultural Experiment Station*

INTRODUCTION

Extensive work has been done to determine the relative value for planting of seeds of various sizes and weights selected by the use of the fanning mill and by hand. Some work along this line has been done by weighing the individual seeds planted. The evidence from some of these experiments is inconclusive, and a study of them raises several questions regarding the seed used, the weather conditions, and the character of the soil for the different seasons, and the technic followed.

(1) Were the differences in weights or sizes of the individual seeds sown sufficiently great in any particular experiment so that a significant variation in yield could be expected?

(2) Were the desired stands of plants usually secured and were they such that the various grades of seed could give expression to their particular value?

(3) May not the rainfall and temperature conditions during any part or throughout the entire growing season have been such that differences in yield, which in all probability would have resulted under ordinary conditions, did not materialize?

(4) What has been the rôle of degree of fertility of the soils on which these trials have been conducted?

(5) Under the conditions which obtained for any particular year was the technic of the experiments such that the experimental error could be ascertained?

These factors, and in some cases others, are necessary considerations in arriving at conclusions from experiments regarding the relative value of various weights of seed for planting.

The data presented in this paper are the results of a 4-year preliminary study of size of individual seeds of wheat in their relation to the resultant plants, to aid in interpreting more accurately trials of similar nature which are now in progress under field conditions.

A careful study of the reactions to environment over a period of years of plants grown from accurately weighed seeds of various sizes ought to give fundamental information of value in this connection.

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In order to obtain the desired data in a form comparable for the 4-year period and easily presented, the biometrical method was used (*Davenport, 1907*).[1]

The subject matter is arranged for presentation in two main divisions. In the first division variability both of the seed used and of the resulting plants is studied. The means, standard deviations, and coefficients of variability are used to this end. In the second division (1) degree of relation between weight of seed and characters of the resultant plants, and (2) degree of interrelation between characters of the resultant plants are shown by correlation coefficients.

REVIEW OF LITERATURE

Love and Leighty (*1914*), working with a pure line of oats, found that biometrical constants—that is, means, standard deviations, coefficients of variability, and correlation coefficients—vary more or less with environmental conditions, such as degree of crowding of the plants and differences in the weather conditions. With conditions not so favorable for plant development, less variability was found in number of culms, total and average number of spikelets, and average number of kernels per spikelet. In average weight of kernels, greater variability was found under unfavorable conditions. When development was arrested by environmental conditions, yield was lowered, not by reduction in average weight per kernels or number of spikelets produced, but by a reduction of the number of kernels per plant, per culm, and per spikelet. Correlations were broadly classified as (a) fluctuating, which vary considerably with environmental conditions, and (b) stable, which vary less from year to year. Between yield of kernels per plant and their average weight no correlation was found in one trial and in two others the coefficients were low—but five and seven times their probable error, respectively. The interpretation is that, for the years when correlation between these two characters occurs, selecting the largest seeds would be securing them from the heaviest yielding plants. Average height of plants, as correlated with average weight per kernel, gave coefficients of 0.219 ± 0.029, -0.023 ± 0.034, and 0.217 ± 0.032, respectively, for three years. For one year there is no correlation. For the two other years the coefficient of correlation is seven times its probable error, which is significant. For the two years the taller plants had a tendency to produce the larger kernels.

Leighty (*1914*) found practically the same correlation coefficients when determinations were made on single culms as when whole plants were used. There was a uniform tendency for the coefficients to be greater when single culms were used. In studying oats grown in hills as compared with that growth in drills rather large differences occurred

[1] Bibliographic citations in parentheses refer to "Literature cited," p. 391-392.

in the correlation coefficients of the same variety for plants grown in the two ways. In any variety, when considerable differences occurred in the coefficients as obtained by the two methods, the lower was secured by using the plants grown in hills. From this it is concluded that differences due to spacing may amount to more than varietal differences.

Variability of yield, number of kernels, number of spikelets, and breaking strength of straw decreased with crowding, while for height the least variability occurred in hills.

Hutchinson (*1913*), in a statistical study of oat plants grown from individually weighed seeds planted at definite distances apart, found medium high positive correlations between weight of seed planted and each of the following characters: Yield of kernels, total weight of plant, number of kernels harvested, height before second leaf, height at 4, 6, and 10 weeks, at heading, and at harvest. No correlation was found between weight of seed planted and average weight of seed harvested. In two trials medium to high positive correlation was found between yield of grain per plant and average weight of kernels harvested, while in another trial no correlation was found between these two characters.

Atkinson (*1912*), using culms as the basis of determinations in a statistical study of eight spring-wheat populations grown under field conditions, obtained correlations as follows: Between yield and average weight of kernel a range from 0.508 ± 0.022 to 0.837 ± 0.009, between average weight of kernel and length of culm a range of from 0.098 ± 0.030 to 0.523 ± 0.022, and between yield and length of culms a range of from 0.217 ± 0.032 to 0.863 ± 0.008.

Meyers (*1912*), investigating the effect of soil fertility on variations and correlations in wheat, found that variability was decreased by increase in fertility, and that all correlations were greatest on the poorer soil.

Roberts (*1912*), working with three pure lines of wheat, found that variability was reduced in favorable growing seasons and concludes that seasonal and soil factors are probably sufficient to overcome hereditary distinctions of yield in good seasons.

Waldron (*1910*), in a statistical study of oats grown under field conditions, found in correlating average weight of kernels with number of kernels per plant a negative correlation of -0.595 ± 0.013. Between average weight of seed and length of head and average weight of seed and length of culm correlation coefficients of -0.511 ± 0.005 and -0.404 ± 0.017, respectively, were found. These correlations indicate that the large kernels are borne by the short plants having short heads and producing a small number of kernels per head.

Love (*1912*), on the other hand, shows positive correlation between height of plant and yield, between height and average weight of kernels, and between yield and average weight of kernels.

Montgomery (*1912*) sowed wheat and oats at different thicknesses and found that, when large and small seeds were planted together and the plants from them grew under competitive conditions, the highest mortality was among the plants from the small seeds. This indicated that the larger seeds produced the stronger plants. It was also found that, under field methods of seeding, there was a reduction of 40 per cent in the stand from planting time to harvest, even when large seeds only were used. The conclusion regarding size of seed is that, since under usual methods of thick seeding a high mortality occurs, it does not seem that fanning-mill selection can increase the efficiency of seed. In comparing two varieties of winter wheat having three grades of seed, lightest light, heaviest heavy, and the seed as it came from the thresher, no difference was found in quantity or quality of grain produced. A similar trial with one variety of oats gave like results.

Kiesselbach and Helm (*1917*) planted hand-selected, large and small seeds alone and in competition with each other. The yield of grain was 11 per cent lower when the small seeds were planted alone and 24 per cent lower when planted in competition with the large seeds. In a 2-year trial of hand-selected large and small seeds of two winter-wheat varieties compared with unselected seed the yield from the large seed was 2.3 per cent greater than that from the unselected seed and 5.4 per cent greater than from the small seed. In a similar trial with two varieties of spring wheat the yield of grain from the large seed was 11.8 per cent greater than that from the unselected seed and 19.5 per cent greater than the yield from the small seed. In these two trials the seed was sown in equal numbers at a normal rate for the large seeds. In a 1-year trial plants from small seeds spaced 6 by 10 inches produced 72 per cent as large a yield of grain as plants from large seeds similarly spaced. As an average for a 4-year trial of large, small, and unselected seeds of Turkey winter wheat and similar trials of Kherson oats covering a 5-year period, and Scotch Fife spring wheat covering a 2-year period, the small seed yielded one-third of 1 per cent less than the large seed when equal weights of seed were sown and 8 per cent less when equal numbers of seeds were sown. In a 12-year trial of the heaviest one-fourth and lightest one-fourth of continuous fanning-mill selected seed sown at the rate of 5 pecks per acre as compared for yield of grain with unselected seed of two varieties of winter wheat considerable variation occurred, but the average results show practically no difference. A similar trial of the same duration with Kherson oats gave somewhat higher yield for the lightest one-fourth as compared with the heaviest one-fourth 6 years out of 12, but the average is slightly in favor of the heaviest one-fourth. In a similar trial with American Banner oats, covering a period of 8 years, the lightest one-fourth yielded higher than the heaviest one-fourth in 6 out of 8 years and averaged 3.67 bushels more for the period of the trial.

Williams and Welton (*1913*) compared the yields for a period of 5 years from large and small seed oats separated by a fanning mill and sown at both a uniform rate in pounds per acre and at a varied rate, the aim of which was to secure the same number of plants per acre. The large seed exceeded the small in yield at both rates of seeding by approximately 4 bushels per acre. The experiment was continued by using large and small seed compared with seed as it came from the threshing machine. The 4-year results show no advantage in favor of the heavy over the ungraded seed at either rate of seeding. At the uniform rate of seeding the small seed was as efficient as either of the two other grades, but at the varied rate it produced 2 bushels less per acre. A comparison was also made of hand-selected primary and secondary kernels of oats definitely spaced. In 3 out of the 5 years the primary seeds proved more efficient.

In a more recent experiment Williams (*1916*) made a comparison in field trials for 8 years of large, small, and unscreened seed of winter wheat with no advantage of large over either of the two other grades. A 6-year trial of hand-selected, large and small seeds from pure lines of wheat showed an advantage in yield of 48 per cent in favor of the former.

Georgeson, Burtis, and Otis (*1897*) in an 8-year trial of three grades of seed oats, heavy, light, and unscreened, found the heavy seed more efficient than unscreened seed by 1 bushel and more efficient than the light seed by 3 bushels per acre.

In an earlier bulletin Georgeson, Burtis, and Otis (*1896*) report the results of a 6-year trial of heavy, light, and unscreened wheat. The heavy and unscreened seed gave practically the same yields, which were superior to the yields from the light seed by 1⅓ and 1½ bushels, respectively.

Zavitz (*1915*) reports the results of six trials with hand-selected, large and small seeds of four varieties of oats grown at seven distances apart. In 90 per cent of the trials the large seeds proved superior. In another trial, covering a period of from 3 to 9 years, hand-selected, large, plump seed yielded in oats 15.4 bushels, in barley 10.6 bushels, in spring wheat 5 bushels, and in winter wheat 6.5 bushels per acre more than small, plump seed of the same variety. Large, plump seed in oats proved more efficient by 7.9 bushels per acre than medium-sized plump seeds.

METHODS OF EXPERIMENTATION

The soil on which our plants were grown is classified by the United States Soil Survey as Hempstead silt loam. The rotation followed on the field where the plants were grown in 1914 and 1915 was as follows: Spring rye, clover, grain, corn with 14 tons of manure per acre, field peas, roots, and spring wheat. The soil is in a moderately high state of fertility. In 1916 and 1917 the plants were grown in a grain-clover-corn rotation, with 6 tons of manure applied preceding the corn. The soil is

not as productive as that on which the plants were grown in 1914 and 1915.

Data on rainfall and temperature are given in Table I. It is necessary to keep in mind the weather conditions during the growing season for each of the four years in order to interpret correctly the results of the work.

TABLE I.—*Normal rainfall and temperature, 1873–1903, with monthly deviations for the growing seasons 1914–1917, inclusive, Minneapolis, Minn.*

	Rainfall.						Temperature.				
	Year.	April.	May.	June.	July.	August.	April.	May.	June.	July.	August.
		Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
Normal	1873–1903	2.50	3.20	3.70	4.20	3.70	47.0	59.0	68.0	72.0	70.0
Deviation from normal	1914	+1.25	−2.12	+4.62	−2.64	+5.01	−1.6	+2.9	− .8	+3.3	− .5
Do	1915	− .57	+ .06	+ .90	+2.11	− .20	+9.3	+5.2	−4.9	−4.6	−4.1
Do	1916	+ .63	+3.05	+ .53	−2.54	−2.03	−3.0	− .4	−4.3	+6.9	+2.4
Do	1917	− .74	+ .32	− .24	+ .25	− .86	−1.5	−2.7	−3.8	+ .9	−2.1

1914.—Seeds were planted on April 19 and some additional ones to make a more desirable number a few days later. Plants were harvested on August 4. With a temperature above normal for May and a rainfall 2 inches below the average, the plants made a luxuriant growth as to height, but produced only a moderate number of tillers. The abundant rainfall and approximately normal temperature of June were favorable for growth, which was checked prematurely by the high temperature and drought during early July. The latter part of July and early August were very wet and stemrust (caused by *Puccinia graminis tritici*) appeared on the plants when the kernels were in the milk stage. This resulted in a shriveling of practically all of the kernels.

1915.—Seeds were planted on April 19. Plants were harvested on August 17. The approximately normal rainfall for April and May, with the exceptionally favorable temperature, allowed the plants to make a luxuriant growth both as to height and tillering. Abundant rainfall during June and July with continued cool weather made conditions ideal for development in the late stages of growth. Stemrust was present in small amounts as the plants reached maturity, but did no damage that could be detected.

1916.—Seeds were planted on April 27. Plants were harvested on August 4. The rainfall was above normal for May and June, with the temperature approximately average during May and considerably below normal for June. In July the weather was dry and hot, conditions which hastened maturity and caused a moderate shriveling of some of the kernels.

1917.—Seeds were planted on April 11. Plants were harvested on July 31. Normal rainfall with continued cool weather up to July and approximately normal for that month made this a favorable year for wheat.

Marquis wheat, which belongs to the group *Triticum vulgare*, was used in the experiment throughout the 4-year period. This wheat was originated at the Central Experimental Farms, Ottawa, Canada, in 1892, by crossing Red Fife and an early-ripening wheat from India received in a sample of a commercial grade, Hard Red Calcutta, followed by a selection of individual plants in 1903. Marquis wheat is widely grown in the hard spring-wheat district in Canada and in the United States. A supply of the seed of this variety was obtained from Canada in 1913 and grown on University Farm that year. From the crop produced on University Farm in 1913, the individual seeds planted in 1914 and 1915 were selected. The seed planted in 1916 was selected from the 1915 crop. In 1917 the seed was taken from a Marquis line established by selecting individual plant 135 from the plants grown in 1914.

The seeds for planting were selected by hand and weighed to the fourth decimal place. If the fourth place was 5 or better, the figure in the third decimal place was increased by 1. As the seeds were weighed they were placed in coin envelopes. The seeds were then arranged in classes according to weight and consecutive numbers entered on the envelopes and at the same time on 3-inch wooden pot labels. The seeds were planted in 4-inch rows, 4 inches apart in the row, with the numbered pot label placed at the proper distance from each. One seed to each 16 square inches made the rate of seeding approximately 30 pounds per acre. For the years 1914 and 1915 the seeds were planted at approximately the same depth; in 1916 and 1917 all seeds were planted at precisely the same depth. For all the years except 1914, when a few additional seeds were planted later to make up the desirable number, all the seeds were planted on the same day. Before using the plants from the seeds sown later in 1914, comparison was made to ascertain whether they affected the results one way or another. Only where height at six weeks is involved was any effect found. Therefore, where height at six weeks is considered, the 219 plants from the first seeding are used. For all other characters, determinations were made on the full number of plants. In order to maintain uniform spacing for all plants, if a seed failed to grow, another plant of the same line was promptly taken from a reserve bed and substituted. These substitute plants were discarded at harvest. Border rows of the same variety were planted on all sides to obviate alley effect.

A few days before harvest, a dry-goods tag bearing the proper number was attached to each plant to identify it and to hold the culms together. All imperfect plants were discarded at this time. As each plant was

pulled, the upper portion was wrapped securely in paper to obviate any shattering. The plants were then hung in the laboratory to dry.

Data were taken on the seedlings and on the mature plants as shown in Table II. The whole plant was the unit used in making the determinations. The total weight of the plant was determined after the root had been severed at the surface of the ground and discarded. The weight of the seed was subtracted from the total weight of the plant for the straw weight determinations. Height of tallest culm was determined by measuring the primary stem from its attachment to the root to the tip of the apical spikelet. The average length of culms, including spikes, and of spikes only, per plant, was determined successively by laying them carefully end to end and taking their respective measurements. Then the total length divided by the number gave the average length of culms and spikes, respectively. Determinations were made on a total of 2,048 plants: 300 in 1914, 571 in 1915, 698 in 1916, and 479 in 1917. All determinations have been checked.

EFFECT OF ENVIRONMENT DURING GROWTH

In Table II are given the means, standard deviations, and coefficients of variability, with their respective probable errors, for each of the characters studied. The seed for the 1914 and 1915 planting was selected from the 1913 crop and for the two years had approximately equal mean weights and standard deviations. The seed planted in 1916 and 1917 was selected from the crop grown in 1915 and 1916, respectively. The mean weight of the seed planted in 1916 was 7.254±0.345 mgm. lower and that for 1917, 14.019±0.352 mgm. lower than the mean weight of the seed used the two previous years.[1]

TABLE II.—*Means, standard deviations, and coefficients of variability for the characters of the wheat studied*

Characters studied.	Means.			
	1914	1915	1916	1917
Weight of individual seeds planted, mgm.	32.580±0.393	33.033±0.260	25,779±0.226	19.014±0.237
Number of days from planting to second leaf	....	....	13.769± .049	26.373± .041
Height of plants at appearance of second leaf .....cm.	6.401± .044	5.286± .039	5.351± .024	6.247± .251
Height of plants at six weeks .....cm.	22.525± .150	23.277± .110	18.515± .076	15.638± .641
Height of tallest culm at maturity..cm.	87.021± .389	113.663± .173	91.043± .149	98.763± .193
Average height of culms at maturity, cm.	68.833± .460	98.419± .272	84.693± .159	94.483± .208
Average length of spikes per plant..cm.	7.638± .039	8.337± .029	7.985± .018	8.032± .020
Total length of culms per plant.....cm.	248.000±4.483	686.821±5.220	225.043±1.740	268.966±2.026
Total length of spikes per plant.....cm.	24.333± .423	54.461± .451	20.627± .165	23.601± .177
Number of culms per plant	3.606± .063	6.977± .053	2.651± .019	2.847± .020
Total yield per plant.....dgm.	47.400±1.049	135.617±1.250	48.022± .391	66.558± .577
Yield of straw per plant.....dgm.	39.600± .894	94.603± .832	30.644± .245	41.299± .357
Yield of kernels per plant.....dgm.	8.153± .209	40.512± .466	17.305± .144	26.007± .227
Number of kernels per plant	55.860±1.081	142.629±1.428	69.183± .549	75.087± .648
Average weight of kernels per plant, mgm.	14.860± .156	27.563± .118	23.732± .056	34.050± .057

[1] The probable error of a difference is found by extracting the square root of the sum of the squares of the probable errors of the two numbers.

TABLE II.—*Means, standard deviations, and coefficients of variability for the characters of the wheat studied*—Continued

Characters studied.	Standard deviations.			
	1914	1915	1916	1917
Weight of individual seeds planted, mgm.	10.079±0.278	9.199±0.184	8.834±0.160	7.695±0.167
Number of days from planting to second leaf	....	....	1.928±.035	1.330±.029
Height of plants at appearance of second leaf, cm.	1.120±.031	1.094±.022	.956±.017	.814±.017
Height of plants at six weeks, cm.	3.282±.106	3.881±.078	2.972±.054	2.079±.045
Height of tallest culm at maturity, cm.	8.527±.275	6.118±.122	5.837±.105	6.275±.136
Average height of culms at maturity, cm.	11.813±.325	9.638±.192	6.226±.112	6.779±.147
Average length of spikes per plant, cm.	.996±.027	1.008±.021	.715±.012	.658±.014
Total length of culms per plant, cm.	115.127±3.170	185.029±3.693	68.139±1.230	65.755±.143
Total length of spikes per plant, cm.	10.861±.299	15.968±.319	6.473±.116	5.768±.125
Number of culms per plant	1.628±.044	1.862±.037	.700±.013	.652±.014
Total yield per plant, dgm.	26.930±.742	44.137±.881	15.320±.276	18.748±.408
Yield of straw per plant, dgm.	22.957±.632	29.460±.588	9.601±.173	11.584±.251
Yield of kernels per plant, dgm.	5.378±.148	16.498±.329	5.674±.102	7.383±.160
Number of kernels per plant	27.753±.764	50.584±1.001	21.514±.388	21.041±.458
Average weight of kernels per plant, mgm.	3.999±.110	4.185±.084	2.211±.039	1.874±.040
Characters studied.	**Coefficients of variability.**			
Weight of individual seeds planted, mgm.	30.940±0.930	27.850±0.597	34.27±0.69	40.47±1.02
Number of days from planting to second leaf	....	....	14.01±.26	5.05±.11
Height of plants at appearance of second leaf, cm.	17.500±.497	20.710±.431	17.88±.33	13.04±.29
Height of plants at six weeks, cm.	14.570±.479	16.070±.342	16.05±.30	13.29±.29
Height of tallest culm at maturity, cm.	9.799±.316	5.380±.107	6.41±.12	6.35±.14
Average height of culms at maturity, cm.	17.160±.486	9.790±.195	7.35±.13	7.18±.16
Average length of spikes per plant, cm.	13.050±.366	12.090±.245	8.96±.16	8.19±.18
Total length of culms per plant, cm.	46.420±1.529	26.940±.575	30.28±.59	24.45±.56
Total length of spikes per plant, cm.	44.640±1.450	29.320±.634	31.38±.62	24.44±.56
Number of culms per plant	45.150±1.475	26.690±.569	28.92±.56	22.91±.52
Total yield per plant, dgm.	56.810±2.007	32.550±.715	31.90±.63	28.17±.66
Yield of straw per plant, dgm.	57.970±2.064	31.150±.679	31.33±.62	28.05±.66
Yield of kernels per plant, dgm.	65.950±2.484	40.720±.938	32.79±.65	28.39±.67
Number of kernels per plant	49.680±1.672	35.470±.792	31.10±.61	28.02±.66
Average weight of kernels per plant, mgm.	37.160±1.156	15.180±.310	9.32±.17	5.50±.12

The somewhat higher productivity of the soil on which the plants were grown in 1914 and 1915, the conditions favoring or retarding growth each season throughout the four years, and the mean weight of the seed planted are very pertinent to the consideration of the variability of the plant characters.

MEANS

The mean for number of days from planting to second leaf was determined for two years only. The greater number of days from planting to second leaf in 1917 as compared with 1916 was due to the lower temperature and drier weather during the period between planting of the seed and emergence in the former year. The means for height in centimeters at appearance of second leaf are 5.286±0.039 for 1915, 5.351±0.024 for 1916, 6.247±0.251 for 1917, and 6.401±0.044 for 1914, with no significant difference between the first two or the last two. One of the highest and

one of the lowest means for height at second leaf was for plants grown on the more productive soil; and likewise one of the highest and one of the lowest for plants grown from the greatest mean weight of seed. Temperature and moisture conditions appear to have had a large influence in rate of development at this early stage.

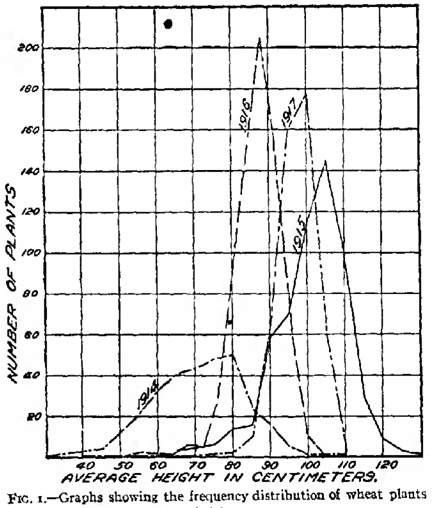

Fig. 1.—Graphs showing the frequency distribution of wheat plants for average height. 1914-1917.

The means in centimeters for height at six weeks are 22.525 ± 0.150 in 1914, 23.277 ± 0.110 in 1915, 18.515 ± 0.076 in 1916, and 15.638 ± 0.641 in 1917, with no significant difference between the first two. This is in the same order as the means for weight of seed planted and in practically the same ratio. The indications are that the influence of the weight of seed on the height of the plants at the six weeks' period was greater than at second leaf.

The means for height of tallest culm at maturity in ascending order of magnitude are 87.021 ± 0.389 for 1914, 91.043 ± 0.149 for 1916, 98.763 ± 0.193 for 1917, and 113.663 ± 0.173 for 1915.

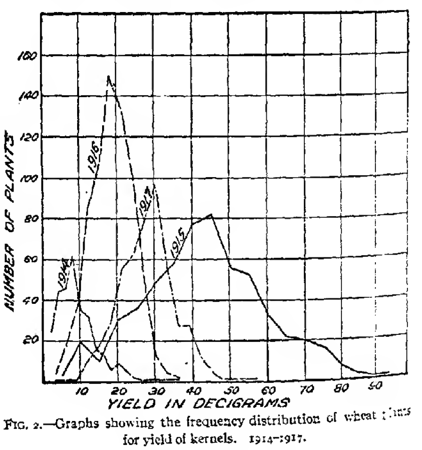

Fig. 2.—Graphs showing the frequency distribution of wheat plants for yield of kernels. 1914-1917.

The means for average height of culms at maturity, average length of spikes, number of kernels, yield of kernels, and total yield per plant follow the same order as those for height of plant. The sequence for average height of culms and yield of kernels per plant representing the

order for this group of characters is shown in the frequency distribution graphs (fig. 1, 2). For each of this group of characters the lowest mean occurs in 1914, the season least favorable to normal development during the latter part of the growing season, and the means for the other three years occur in ascending order according to the favorableness as a whole of the growing season for wheat, 1916, 1917, and 1915, respectively.

The means for number of culms per plant are 2.651±0.019 in 1916, 2.847±0.020 in 1917, 3.606±0.063 in 1914, and 6.977±0.053 in 1915. The means for yield of straw, total length of culms, and total length of spikes per plant are in practically the same order as those for number of culms.

For number of culms per plant representing this group of characters, the order of the means is shown in the frequency distribution graph (fig. 3). The magnitude of the means for this group of characters is largely dependent on the favorableness of conditions for growth during the early part of the season. This order is 1916, 1917, 1914, and 1915, respectively.

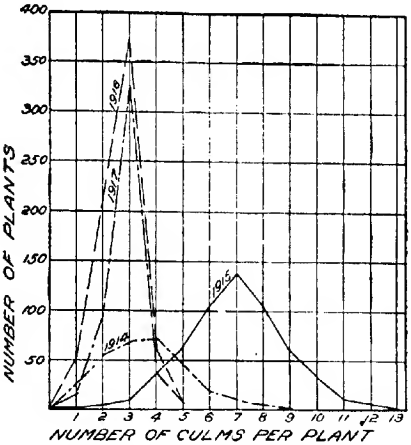

FIG. 3.—Graphs showing the frequency distribution of wheat plants for number of culms. 1914–1917.

Comparison of the order of the means for the two groups of characters throughout the 4-year period shows the means for the group of characters represented by height of tallest culm, which are dependent for their development upon conditions during the latter part of the growing season, follow the order of optimum conditions during that time; and that the means for the other group of characters represented by number of culms, which develop largely during the early part of the season, follow the order of the best conditions for early growth.

The means for average weight of kernel are 14.860±0.156 in 1914, 23.732±0.056 in 1916, 27.563±0.118 in 1915, and 34.050±0.057 in 1917. The frequency distribution graph (fig. 4) shows this order. In 1914 and 1916, the sequence of the means for average weight of kernels is the same as yield of grain and number of kernels; but in 1915 and 1917 in the reverse order. The kernels of the 1914 crop were shriveled, as were also some of those of the 1916 crop. In 1915 and 1917 all kernels were well filled. Under the especially favorable conditions which prevailed

throughout the entire growing season in 1915 a larger number and greater yield of kernels was produced, but the average weight of the kernels was not as great as in 1916, when conditions favored a more normal development.

As indicated by the means, the various characters studied responded more or less directly to external conditions which prevailed while each was making its most rapid development. The number of culms per plant and the yield of straw were influenced most by environment during the early part of the growing season, and number, yield, and average weight of kernels by environment during the latter part of the growing season. When growth was retarded or stopped by environmental conditions, lower yields of straw resulted from a reduction in the number, total, or average length of culms per plant; and lower yields of grain, from a reduction in the number of kernels; and for 1914 and 1916 only, a lower average weight of kernels. The kernels were more or less shriveled in 1914 and 1916. When the grain developed normally, as in 1915 and 1917, the lower yield of kernels in 1917 was accompanied by a higher average weight per kernel.

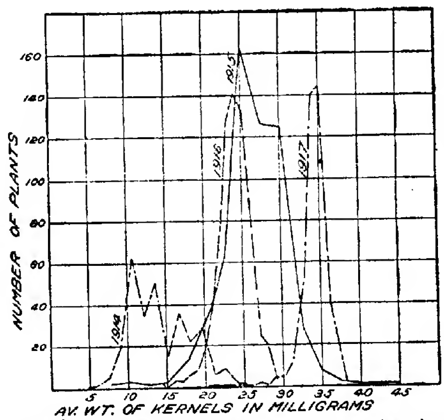

FIG. 4.—Graphs showing the frequency distribution of wheat plants for average weight of kernels. 1914–1917.

STANDARD DEVIATIONS

The standard deviations for number of days from planting to second leaf are 1.928±0.035 in 1916 and 1.330±0.029 in 1917.

For height at second leaf the two highest means are accompanied by the highest and lowest standard deviations. Better root development in 1917 during the prolonged cool period intervening between the time of planting the seed and emergence, which may have permitted the plants to begin growth at the surface more nearly at the same time, is a possible explanation of the lower standard deviation accompanying the higher mean.

The standard deviations for height at six weeks are in the same order as the means, with significant differences between any two except those in 1914 and 1916. The variability of average height at second leaf and at six weeks, measured by the standard deviations, is comparatively low during the 4-year period.

For height of tallest culm, average height of culms, and average length of spikes the means in 1914 are lower, but the standard deviations are as high or higher than the standard deviations for these characters in any of the three other years. The comparatively high variability in 1914 of average height of culms is indicated on the frequency distribution graph (fig. 1). The differences in centimeters between the height of tallest culm and average length of culms are 18.188±0.602 in 1914, 15.214±0.322 in 1915, 6.350±0.218 in 1916, and 4.280±0.284 in 1917. The greater difference in height between the tallest culm and the average of the culms in 1914 indicates that the drouth in early July and the stemrust in late July and early August of that year prevented the secondary culms from approaching in height the main culm as closely as they did the three other years. This would tend to increase the variability of these two characters as well as that of average length of spikes. After making due allowance for the abnormal conditions in 1914, it is of interest to note the comparatively low variability of height of tallest culm as indicated by the standard deviations.

For number and average weight of kernels and total yield of plants the means were lowest in 1914, but the standard deviations for these characters in the same year were either next to the highest or equal to the highest.

The mean for yield of kernels in 1914 was reduced materially, owing to the drought and black stemrust, and the standard deviation is also low.

The mean for average weight of kernels per plant was highest in 1917, but it is accompanied by the lowest standard deviation in the 4-year period. This is indicated on the frequency distribution graph (fig. 4).

For number of culms, total length of culms, total length of spikes, and weight of straw per plant the means for 1914 were either almost equaled or exceeded by those for 1915 and 1916, more favorable years; but the standard deviations are equaled or exceeded only by those for the 1915 crop.

In general, the standard deviations tend to follow the same order as the means, the variability being greatest where the means are the greatest, due in both instances to favorable conditions for development. Exceptions to this tendency may be due in part to the frequent smaller differences between standard deviations as judged by their probable errors compared with the differences between means as judged by their probable errors. Average weight of kernel had the highest mean in 1917 accompanied by the lowest standard deviation, which is an exception. A number of exceptions occurred in 1914, owing to the very favorable condition for development during the first part and the opposite conditions during the latter part of the growing season.

COEFFICIENTS OF VARIABILITY

With few exceptions the coefficients were higher in 1914 than in the three other years. This corresponds to the generally lower means for that year.

As is indicated by the coefficients, number of days to second leaf and average weight of kernels in 1917 varied least, but each character was highly variable from year to year. Height at six weeks, height at maturity, average height of culms, and average length of spikes were comparatively low in variability each year and from year to year. This confirms similar indications by the standard deviations.

As indicated by the coefficients of variability, the greatest variation in the 4-year period occurred in 1914 for total weight per plant, yield of of straw, and yield of kernels.

CORRELATIONS

Correlation coefficients were determined for weight of seed used and each of the resultant plant characters listed in Table III. The assembled data also offered the opportunity to study the interrelation of plant characters for which the coefficients of correlation are presented in Table XIII. Since it was not considered feasible to present all the correlation tables, the selection for presentation was confined to those likely to be of most value and interest. (See Tables IV–XI; XIV–XXI.)

TABLE III.—*Coefficients of correlation between weight of seed and characters of the resultant plants*

Characters studied.	1914	1915	1916	1917
Number of days from planting to second leaf	....	....	−0.484±0.019	−0.634±0.018
Height of plants at appearance of second leaf ... cm	0.146±0.038	0.114±0.027	.169± .024	.259± .028
Height of plants at six weeks ... cm	.356± .040	.445± .022	.649± .014	.712± .015
Height of tallest culm at maturity ... cm	.196± .037	− .037± .028	.311± .023	.074± .030
Average height of culms at maturity ... cm	.093± .038	− .099± .028	.192± .024	.118± .030
Average length of spikes per plant ... cm	.007± .038	− .193± .027	.126± .025	.202± .029
Total length of culms per plant ... cm	.251± .036	.066± .028	.460± .020	.395± .026
Total length of spikes per plant ... cm	.259± .036	− .018± .028	.442± .020	.417± .025
Number of culms per plant	.232± .036	.116± .027	.420± .021	.398± .025
Total weight per plant ... dgm	.229± .036	.064± .028	.423± .021	.435± .024
Yield of straw per plant ... dgm	.226± .036	.046± .028	.407± .021	.401± .025
Yield of kernels per plant ... dgm	.143± .038	.088± .028	.445± .020	.478± .024
Number of kernels per plant	.246± .036	.076± .028	.458± .020	.465± .023
Average weight of kernels per plant, mgm	− .062± .038	.086± .028	.055± .025	.141± .030

TABLE IV.—*Weight in milligrams of individual seeds planted correlated with height in centimeters of plant at six weeks. 1914*

Height of plant at six weeks (cm.).	Weight of individual seeds planted (mgm.).										Frequency.
	13	15	17	19	21	23	25	27	29	31	
18		1			3	1					5
20	1		2	4	3	2					12
22		2		4	4	4	1				15
24			2	5	5	5	2		1		20
26			1	1	7	5	5	1	1		21
28			3	2	4	4					13
30			1	1		2	2				6
32				1	1	2	2	1			7
34					2	4	2	1			9
36					2	9	2	1			14
38			1	1	3	2	2	1	4	1	15
40				3	6	6	3	2	3		23
42		1		2	1	9	4	1	1		19
44				3	4	2	6	4	1		20
46		1	1	1	1	6	1	1	2	1	15
48						1		1			2
50							1				1
52					1		1				2
Frequency	1	5	11	28	47	64	34	14	13	2	219

Correlation $=0.356 \pm 0.040$.

TABLE V.—*Weight in milligrams of individual seeds planted correlated with height in centimeters of plant at six weeks. 1915*

Height of plant at six weeks (cm.).	Weight of individual seeds planted (mgm.).														Frequency.
	9	11	13	15	17	19	21	23	25	27	29	31	33	35	
16				1	4		1	1							7
18			1	1	3	2	1								8
20				3	6	7	8	6	5						35
22	1		1	1	7	9	13	15	5						52
24			1		8	4	17	25	6	3					64
26						4	8	10	14	8	1				45
28				1		3	4		2	1					11
30			1			2	6	1	8	1	1				20
32					6	1	4	15	15	6					47
34				1	2	2	4	7	10	8	3	1			38
36						1	2	6	6	4	2				21
38					1			4	3		2				10
40				1		4	10	6	10	9	6				46
42			1		1	6	4	7	12	15	14	5			65
44					1	2		4	7	12	19	2		2	49
46			1		4	2	2	6	9	9	1	1			35
48						1	1	2	3	1	2				10
50				1	1	1	2			2	1				8
Frequency	1		6	10	44	51	87	115	115	79	52	9		2	571

Correlation $=0.445 \pm 0.022$.

TABLE VI.—*Weight in milligrams of individual seeds planted correlated with height in centimeters of plant at six weeks. 1916*

Height of plant at six weeks (cm.).	Weight of individual seeds planted (mgm.): 9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	Frequency.
8	...	...	1	2	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	4
10	1	...	...	2	4	2	4	2	...	...	...	...	...	...	...	...	...	...	...	15
12	...	...	...	1	7	9	6	2	3	...	1	...	...	...	...	...	...	...	...	29
14	...	1	...	1	5	5	13	11	7	3	2	...	...	...	...	...	...	...	...	48
16	...	...	...	...	4	5	8	16	7	9	6	3	...	1	...	...	...	...	...	59
18	...	...	1	...	1	1	4	8	4	6	9	...	1	1	...	...	...	...	...	36
20	...	...	...	...	...	...	2	2	7	4	6	2	1	1	...	...	...	...	...	25
22	...	...	...	1	2	...	2	6	5	11	6	2	3	...	...	...	...	...	...	38
24	...	...	...	...	...	...	3	7	5	9	21	6	13	2	2	...	...	...	...	68
26	...	...	...	...	...	1	3	6	6	11	20	17	7	5	1	...	...	...	...	77
28	...	...	...	...	1	2	...	3	4	5	11	13	9	9	4	1	...	...	...	62
30	...	1	...	...	...	3	...	...	3	2	12	9	9	2	2	...	1	...	...	44
32	...	1	...	...	...	1	1	...	...	...	1	4	3	1	2	2	1	...	...	17
34	...	...	...	...	...	...	1	2	3	4	3	7	5	3	1	...	2	...	1	32
36	...	...	...	...	...	1	...	...	1	3	3	5	10	8	9	4	1	...	...	45
38	...	...	...	...	1	...	2	1	...	...	...	11	11	8	13	...	...	...	...	47
40	...	...	...	...	...	...	...	1	2	1	2	4	7	6	4	3	...	...	...	30
42	...	...	...	...	1	...	1	1	1	...	1	2	3	3	3	...	...	...	...	16
44	...	...	...	...	...	...	...	1	...	...	...	1	...	2	1	1	...	...	...	6
Frequency	1	3	2	7	27	30	50	69	58	68	104	86	82	52	42	11	5	...	1	698

Correlation=0.649±0.015.

TABLE VII.—*Weight in milligrams of individual seeds planted correlated with height in centimeters of plant at six weeks. 1917*

Height of plant at six weeks (cm.).	Weight of individual seeds planted (mgm.): 6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Frequency.
6	1	...	...	...	2	4	8	8	2	...	...	...	...	...	...	25
8	...	...	...	...	1	1	8	10	9	3	...	...	...	...	...	32
10	...	...	...	...	...	...	8	6	14	9	2	2	...	...	...	41
12	...	...	...	...	...	...	...	2	11	14	5	...	...	...	...	32
14	...	...	...	...	1	...	...	2	7	8	15	1	...	...	...	34
16	...	...	...	...	...	...	1	2	3	8	21	4	...	...	...	39
18	...	...	...	...	1	...	...	...	...	9	15	7	1	...	...	33
20	...	...	...	...	...	...	...	...	2	8	13	11	5	...	...	39
22	...	...	...	...	...	...	...	2	4	4	8	9	9	1	...	37
24	...	...	...	...	...	...	1	2	1	4	10	2	12	4	...	36
26	...	...	...	...	...	...	1	...	1	3	4	11	12	6	...	38
28	...	...	...	...	...	1	...	...	...	1	7	11	12	3	1	36
30	...	...	...	1	...	...	...	...	1	2	5	9	6	7	1	32
32	...	...	...	...	...	...	...	...	...	...	3	6	10	5	1	25
Frequency	1	...	...	1	5	6	27	34	55	73	108	73	67	26	3	479

Correlation=0.712±0.015.

TABLE VIII.—*Weight in milligrams of individual seeds planted correlated with yield in decigrams of kernels per plant. 1914*

Yield of kernels per plant (dgm.)	Weight of individual seeds planted (mgm.) 1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	Frequency.
14		1	1		1														3
16		1		1	2														4
18	7	3	5	3	1		1												10
20	4	5	3	5		1	2	2		1									23
22		3	9	6	3	5	1					1							28
24	2	5	2	8		5	1	1	1	1	1								27
26		4	2	2	2	1	3	1											15
28	1	1	2	2					1										7
30		1		2	3	1			1										8
32				3	1		1			1									0
34	1	1	2	1		4		1	1										11
36			2	2	2	4		1	1	2									14
38	1	3	1	4		2	1	2			3		1						18
40		7	2	6	4	2	2	1	1	2	1	1			1			1	31
42	3	2	4	6	0	3	3	2		1									30
44	2	4	8	5	4		2				1								26
46	1	3	2	3	4	4		2		1									20
48	2				2		1												5
50		1	1	2															4
Frequency	24	45	46	61	35	32	18	13	6	9	6	2	1		1			1	300

Correlation = 0.143 ± 0.038.

TABLE IX.—*Weight in milligrams of individual seeds planted correlated with yield in decigrams of kernels per plant. 1915*

Yield of kernels per plant (dgm.)	Weight of individual seeds planted (mgm.) 2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5	Frequency.
16	1	1				1		1	2			1									7
18		1			1	1	2		2		1										8
20		2	1	1	3	6	4	4	2	2	7		2		1						35
22	2		1	1	4	2	5	7	4	7	6	7	2	2	1	1					52
24		4	1	2	3	8	8	5	8	10	7	2	4	2							64
26			1			3	5	7	9	4	7	3		3	1		1		1		45
28			1	1	1	1	2	3	1					1							11
30		1		1	3	3	2	1	2	2	3		1				1				20
32		1	2	3		2	5	13	8	5	3	3	1	1							47
34		1		3	4	6	5	4	7	5	1		1	1							38
36					2	4	2	2	5	1	2	2	1								21
38		1			1		1	3	1			1			1	1					10
40		1		5	3	4	4	7	11	1	3	1	2	3	1						46
42		4	1	6	7	6	4	9	6	4	7	3	2	2	3					1	65
44		1	1	1	1		5	7	9	7	3	4	5	3	1	1					49
46		1	1	5	3	2	2	2	5	7	1	3			3						35
48							1	1		1	1	1			2	2		1			10
50				1			1	1				1		1	1	1				1	8
Frequency	3	19	10	30	36	49	58	77	82	56	52	32	21	19	15	6	2	1	1	2	571

Correlation = 0.088 ± 0.028.

TABLE X.—*Weight in milligrams of individual seeds planted correlated with yield in decigrams of kernels per plant. 1916*

Yield of kernels per plant (dgm.)	Weight of individual seeds planted (mgm.) 2.25	3.75	5.25	6.75	8.25	9.75	11.25	12.75	14.25	15.75	17.25	18.75	20.25	21.75	23.25	24.75	26.25	27.75	29.25	30.75	32.25	33.75	Frequency.
8	...	...	1	...	1	1	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	4
10	1	...	...	...	4	2	1	2	2	2	1	...	...	...	...	...	...	...	...	...	...	...	15
12	...	...	3	1	2	7	3	4	5	1	...	1	1	1	...	...	...	...	...	...	...	...	29
14	...	...	1	1	5	4	12	7	5	6	2	3	1	...	1	...	...	...	...	...	...	...	48
16	...	1	2	2	1	6	5	4	6	8	8	8	4	1	2	...	...	1	...	...	...	...	59
18	...	...	...	1	1	3	2	2	7	4	4	4	6	...	1	...	...	1	...	...	...	...	36
20	...	...	...	...	1	...	...	4	2	6	6	2	3	1	...	...	...	...	...	...	...	...	25
22	...	1	...	...	1	1	4	3	4	3	5	3	6	1	2	2	...	...	...	...	...	...	38
24	...	...	...	1	...	...	2	5	9	6	7	10	4	6	5	7	3	2	1	...	...	...	68
26	...	...	1	1	1	6	3	3	5	7	11	6	8	12	4	7	1	1	...	...	...	...	77
28	1	1	...	...	1	1	4	2	4	7	5	2	10	12	2	8	...	2	...	...	...	...	62
30	1	...	1	...	2	1	1	5	4	3	7	10	2	1	5	1	...	...	...	...	...	...	44
32	1	...	...	1	...	1	...	...	...	2	3	3	2	1	1	2	...	...	...	...	...	...	17
34	...	...	...	...	...	...	2	1	...	2	2	6	3	5	3	3	2	...	...	1	1	1	32
36	...	...	...	...	...	1	2	2	3	2	2	9	2	7	6	4	1	4	...	...	...	...	45
38	...	...	1	...	1	...	1	...	...	2	6	8	7	3	6	2	6	2	1	...	1	...	47
40	...	1	...	...	...	2	1	...	1	1	3	2	1	4	5	1	5	...	1	1	...	1	30
42	...	1	...	2	...	...	1	1	...	...	1	...	1	3	...	3	1	1	...	1	...	...	16
44	...	...	...	...	...	...	...	...	...	...	...	1	2	1	1	...	...	...	...	1	...	...	6
Frequency	4	5	10	12	21	36	44	46	57	62	73	78	63	59	44	40	19	14	3	4	2	2	698

Correlation = 0.445 ± 0.020.

TABLE XI.—*Weight in milligrams of individual seeds planted correlated with yield in decigrams of kernels per plant. 1917*

Yield of kernels per plant (dgm.)	Weight of individual seeds planted (mgm.) 1.5	4.5	7.5	10.5	13.5	16.5	19.5	22.5	25.5	28.5	31.5	34.5	37.5	40.5	43.5	46.5	49.5	52.5	55.5	Frequency.
6	1	...	...	3	7	4	6	2	1	1	...	...	...	...	...	...	...	...	...	25
8	1	...	1	6	2	2	8	6	3	3	...	...	...	...	...	...	...	...	...	32
10	...	...	...	...	3	8	9	7	7	4	3	...	...	...	...	...	...	...	...	41
12	...	...	...	...	...	7	4	4	10	2	2	2	1	...	...	...	...	...	...	32
14	...	...	...	1	1	2	2	6	5	9	5	...	1	2	...	...	...	...	...	34
16	...	...	...	1	1	...	4	3	8	5	8	5	3	1	...	...	...	...	...	39
18	...	...	...	...	...	...	4	2	5	13	4	1	4	...	...	...	...	...	...	33
20	...	...	...	...	...	1	6	4	9	9	8	1	1	...	...	...	...	...	...	39
22	...	...	...	...	...	...	1	8	10	9	4	1	1	2	1	...	...	...	...	37
24	...	...	...	...	2	1	3	8	4	9	6	1	2	...	...	...	...	...	...	36
26	...	...	...	...	2	1	3	6	4	11	7	2	1	1	...	...	...	...	...	38
28	...	...	...	...	...	2	4	3	3	8	6	5	3	1	...	...	1	...	...	36
30	...	1	...	...	...	...	1	3	4	5	4	6	4	2	1	...	...	...	1	32
32	...	...	...	...	...	1	...	...	5	5	1	3	6	2	1	1	...	...	...	25
Frequency	2	1	1	11	18	29	55	62	78	93	58	27	27	11	3	1	1	...	1	479

Correlation = 0.478 ± 0.023.

RELATION OF WEIGHT OF SEED USED TO THE RESULTANT PLANT CHARACTERS

Inspection of the coefficients given in Table III shows that, with certain exceptions, the correlation coefficients in 1914 and 1915 are lower than those for the same characters in 1916 and 1917.

The relatively low correlation in 1914 and 1915 corresponds to the comparatively high variability in these two years, both of which are due in part to (a) the extreme climatological and pathological conditions, (b)

the somewhat higher productivity of the soil, and (c) the higher mean and greater range in weight of seed planted.

Correlation coefficients for number of days from planting to second leaf were determined in 1916 and 1917 only. The correlation coefficients are relatively high, indicating that the plants from the heavier seeds reach the second leaf stage sooner than the plants from the lighter seeds. Correlation is highest in 1917, the year in which the mean weight of the seed was the lowest.

Weight of seed correlated with height of plants at second leaf gave coefficients varying from 0.114±0.027 in 1915 to 0.259±0.028 in 1917 and correlated with height at six weeks, a variation from 0.356±0.040 in 1914 to 0.712±0.015 in 1917. In each of the four years the coefficients as compared with their probable errors show a fair correlation for height at second leaf and a considerably higher correlation for height at six weeks. This indicates that at the appearance of the second leaf the greater food supply available to the plants from the larger seeds had not yet exerted its influence. An extreme difference of 0.145±0.038 in the coefficients for height at second leaf and 0.356±0.042 for height at six weeks during the 4-year period shows that correlation between weight of seed and both of the characters was influenced considerably by environment.

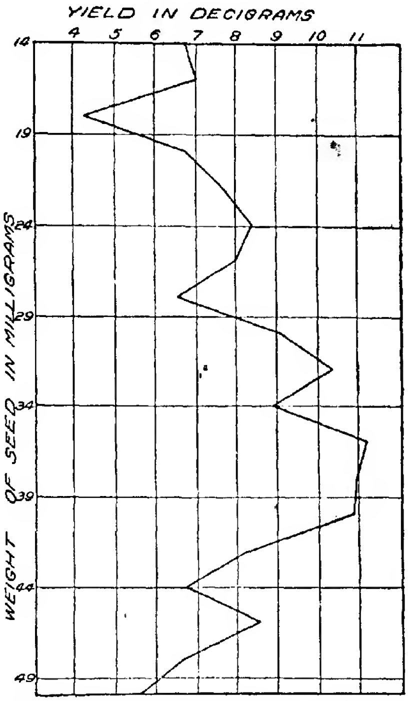

FIG. 5.—Graph showing regression for weight of seed and yield of kernels per wheat plant in 1914.

Between weight of seed and height of tallest culm at maturity the correlation coefficients are −0.037±0.028 in 1915, 0.074±0.030 in 1917, 0.196±0.037 in 1914, and 0.311±0.023 in 1916. As indicated by the

coefficients in terms of their probable errors, there was practically no correlation between weight of seed and height of tallest culm at maturity in 1915 and 1917 and a good correlation in 1914 and 1916. The coefficients of correlation between weight of seed and average height at maturity are 0.093 ± 0.038 in 1914, −0.099 ± 0.028 in 1915, 0.118 ± 0.030 in 1917, and 0.192 ± 0.024 in 1916. The coefficients of correlation of the two characters range from 2.45 times the probable error in 1914 to 8 times the probable error in 1916.

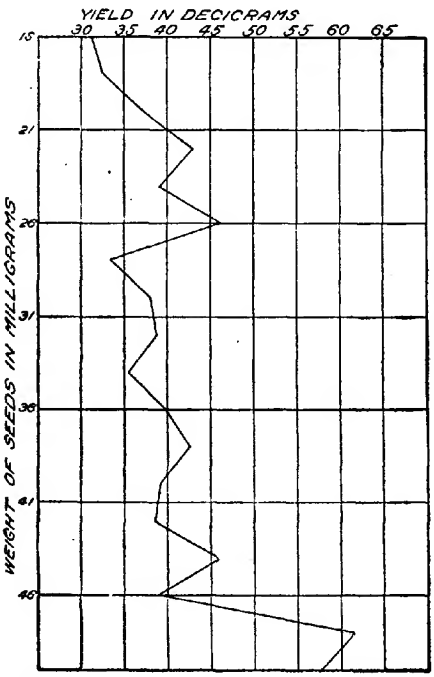

FIG. 6.—Graph showing regression for weight of seed and yield of kernels per wheat plant in 1915.

Between weight of seed planted and average weight of kernels harvested the coefficients are −0.062 ± 0.038 in 1914, 0.055 ± 0.025 in 1916, 0.086 ± 0.028 in 1915, and 0.141 ± 0.030 in 1917. While the coefficients are low in each of the four years, a slight correlation is indicated in 1914 and 1916, and in 1915 the coefficient is three times and in 1917 4.7 times their respective probable errors. The most significant correlation between the two characters occurred in 1917 when the seeds planted were selected from a line established through the selection of individual plant 135 of the 1914 crop. Since the results indicate that the Marquis wheat used in this experiment was not homozygous for weight of seed, it can not be considered a pure line for this character.

The coefficients for weight of seed planted correlated with yield of kernels per plant are 0.088 ± 0.028 in 1915, 0.143 ± 0.038 in 1914, 0.445 ± 0.020 in 1916, and 0.478 ± 0.023 in 1917. In 1914 and 1915 the coefficients of correlation are low, 3.1 times and 3.8 times their probable errors, respectively, with no significant difference between them. The coefficients in 1916 and 1917 are considerably greater than those in 1914 and 1915.

The weight classes for the individual seeds planted, number of plants in each class harvested, and the average yield, in decigrams, of kernels per plant are given in Table XII. This gives the same data with respect to yield from kernels of different weights as is given in the correlation tables but in more direct form. That increase in weight of seed planted was not consistently followed by increased yield of kernels is evident.

TABLE XII.—*Weight classes of seeds planted and average yield of kernels per plant*

Weight classes of individual seeds planted.	1914		1915		1916		1917	
	Number of plants harvested.	Average yield per plant.	Number of plants harvested.	Average yield per plant.	Number of plants harvested.	Average yield per plant.	Number of plants harvested.	Average yield per plant.
Mgm.		*Dgm.*		*Dgm.*		*Dgm.*		*Dgm.*
6							25	16.38
8					4	9.00	32	18.28
10					15	11.25	41	21.77
12					29	11.72	32	23.91
14	3	5.67			48	12.84	34	26.21
16	4	7.00	7	31.07	59	14.89	39	28.01
18	20	4.20	8	32.50	36	15.88	33	28.23
20	23	6.74	35	37.21	25	16.21	39	26.50
22	28	7.64	52	42.98	38	15.91	37	27.93
24	27	8.26	64	38.98	68	18.95	36	26.08
26	15	7.93	45	46.28	77	17.89	38	26.84
28	7	6.43	11	33.36	62	18.52	36	29.08
30	8	9.00	20	38.00	44	16.47	32	31.22
32	6	10.33	47	38.88	37	17.25	25	32.70
34	11	8.82	38	35.39	32	21.14		
36	14	11.14	21	39.88	45	20.08		
38	18	10.89	10	42.50	47	20.86		
40	31	10.81	46	39.02	30	20.90		
42	30	8.20	65	38.42	16	18.94		
44	26	6.62	49	45.97	6	22.50		
46	20	8.50	35	38.79				
48	5	6.60	10	61.50				
50	4	5.50	8	57.50				

Regression for yield of kernels in each of the four years is shown in figures 5, 6, 7, and 8. Regression for yield was consistently greater in 1916 (fig. 7) for the seeds up to 24 mgm. than for the larger seeds. Apparently increase in amount of endosperm in 1916 and 1917 up to the weights of seeds indicated gave more uniformly proportionate increases in yield than were given by increases in endosperm beyond these amounts.

Very similar to the correlations between weight of seeds and yield of kernels in each of the four years are those between weight of seed and total length of culms, total length of spikes, number of culms, total yield, yield of straw and number of kernels per plant.

The correlation between weight of seed and plant characters at maturity in 1916 and 1917 was, for height of tallest culm, low and variable; for average height of culms and average length of spikes, low but less variable; and for total length of culms, total length of spikes, number of culms, total weight, and yield of grain and straw, medium, with little fluctuation. The only significant difference in 1916 and 1917 between coefficients for weight of seed planted and characters at maturity is

that between those for height of tallest culm. Therefore it is evident that on soil of medium productivity, the more favorable weather conditions in 1917 as compared with that in 1916 did not influence correlation to any marked extent.

In 1914 and 1915 the coefficients for all plant characters at maturity are comparatively low; and, with the exception of those for number of culms, yield of kernels, and average weight of kernels, they are significantly lower in 1915 than in 1914. This difference is due to the highly favorable environmental conditions in 1915.

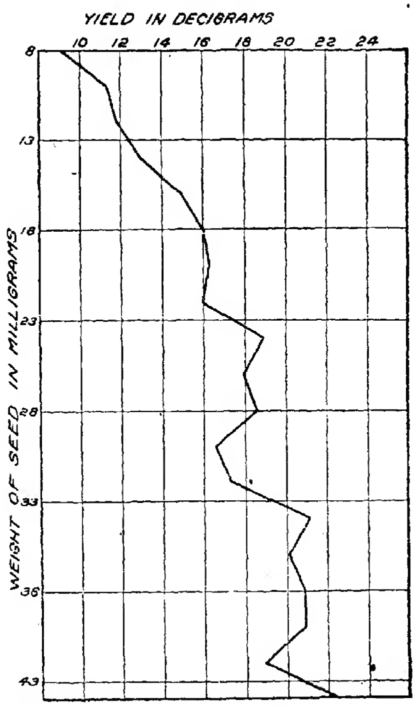

Fig. 7.—Graph showing regression for weight of seed and yield of kernels per wheat plant in 1916.

Considered as a whole, there is a distinct tendency toward correlation between weight of seed sown and the characters of the resultant plants. However, the correlation, even under average conditions, is not high in any instance, and is subject to the influence of environmental conditions to so marked an extent that with some characters the relation may be obliterated entirely; and with other characters, including yield, may be made so slight that under ordinary conditions of experiment no relation could be detected.

INTERRELATION OF PLANT CHARACTERS

The coefficients given in Table XIII show that only in the group where yield of kernels is correlated with other characters is there a general tendency toward less correlation in 1914 and 1915 than in 1916 and 1917. This condition although much less marked, is similar to that found when weight of seed was correlated with plant characters at maturity and is

due to the differences in environment between the first two and last two years.

TABLE XIII.—*Coefficients of correlations between plant characters*

Characters studied.	1914	1915	1916	1917
Yield of kernels per plant (dgm.) and—				
Number of kernels per plant	0.851±0.010	0.881±0.006	0.952±0.002	0.973±0.001
Average weight of kernels per plant . mgm.	.550± .027	.504± .021	.370± .022	.306± .027
Number of culms per plant	.500± .029	.669± .015	.818± .008	.824± .009
Average height of culms per plant . cm.	.384± .033	.303± .025	.478± .019	.452± .024
Average length of spikes per plant . cm.	.357± .034	.344± .024	.459± .020	.591± .020
Total length of spikes per plant . cm.	.630± .023	.808± .009	.910± .004	.911± .005
Number of culms per plant and—				
Average length of spikes per plant . cm.	.061± .038	.024± .028	.039± .025	.236± .029
Total length of spikes per plant . cm.	.872± .009	.839± .008	.958± .002	.940± .003
Average weight of kernels per plant (mgm.) and—				
Number of kernels per plant	.137± .038	.192± .027	.160± .024	.160± .030
Number of culms per plant	.071± .038	.137± .027	−.054± .025	−.009± .030
Average length of spikes per plant . cm.	.153± .038	.120± .027	.551± .017	.411± .025
Total length of spikes per plant . cm.	.001± .038	.159± .027	.079± .025	.091± .030
Average height of culms per plant (cm.) and—				
Number of kernels per plant	.257± .036	.339± .025	.364± .022	.431± .025
Average weight of kernels per plant . mgm.	.458± .030	.071± .028	.648± .014	.426± .025
Number of culms per plant	.195± .037	.092± .028	.040± .025	.205± .029
Average length of spikes per plant . cm.	.315± .035	.419± .023	.775± .010	.668± .017
Total length of spikes per plant . cm.	.036± .038	.260± .026	.235± .024	.351± .027
Height of plants at appearance of second leaf (cm.) and—				
Height of plants at six weeks . cm.	.406± .038	.467± .022	.470± .019	.466± .024
Height of tallest culm at maturity . cm.	.380± .033	.270± .026	.272± .023	.211± .029
Height of plants at six weeks (cm.) and—				
Height of tallest culm at maturity . cm.	.399± .038	.236± .026	.523± .018	.314± .027

TABLE XIV.—*Yield in decigrams of kernels per plant correlated with average weight in milligrams of kernels per plant. 1914*

Average weight of kernels per plant (mgm.).	Yield of kernels per plant (dgm.). 5.25	6.75	8.25	9.75	11.25	12.75	14.25	15.75	17.25	18.75	20.25	21.75	23.25	24.75	26.25	Frequency.
1		2	1	2	8		7		2	1	1					24
3	1		1	7	18	5	5	1	5	1	1					45
5			3	4	11	8	10	2	3	1	4					46
7			1	6	10	9	12	6	7	4	3		2		1	61
9				2	10	7	5	1	5	1	4					35
11					4	2	6	3	6	3	5	1	2			32
13					1	2	3	2	4	4		2				18
15							2		2	2	5	1		1		13
17						1			1	1		1	2			6
19					1		1		1	1	2		2	1		9
21									1	2	1	1	1			6
23										1	1					2
25											1					1
27																
29											1					1
31																
33																
35															1	1
Frequency	1	2	6	21	63	34	51	15	37	22	29	6	9	2	2	300

Correlation = 0.550±0.027.

TABLE XV.—*Yield in decigrams of kernels per plant correlated with average weight in milligrams of kernels per plant. 1915*

Average weight of kernels per plant (mgm.).	Yield of kernels per plant (dgm.). 8.75	11.25	13.75	16.25	18.75	21.25	23.75	26.25	28.75	31.25	33.75	36.25	38.75	41.25	43.75	46.25	Frequency.
2.5	....	....	....	1	....	1	1	....	....	....	....	....	....	....	....	....	3
7.5	....	1	....	....	1	4	2	6	2	1	1	1	....	....	....	....	19
12.5	....	....	1	....	1	3	....	2	2	1	....	....	....	....	....	....	10
17.5	2	1	....	1	2	1	5	10	5	2	1	....	....	....	....	....	30
22.5	....	1	1	1	2	7	6	10	3	5	....	....	....	....	....	....	36
27.5	....	....	....	....	3	4	12	17	7	4	1	....	1	....	....	....	49
32.5	....	....	....	....	2	1	14	17	14	8	2	....	....	....	....	....	58
37.5	....	....	....	....	1	6	13	27	16	11	2	1	....	....	....	....	77
42.5	....	....	....	....	....	4	5	31	22	18	1	1	....	....	....	....	82
47.5	....	....	....	....	....	1	3	24	13	12	2	1	....	....	....	....	56
52.5	....	....	....	....	....	....	1	10	20	15	5	1	....	....	....	....	52
57.5	....	....	....	....	....	....	....	2	12	13	3	....	1	1	....	....	32
62.5	....	....	....	....	....	....	....	4	4	12	....	....	....	....	....	1	21
67.5	....	....	....	....	....	....	....	4	3	9	2	1	....	....	....	....	19
72.5	....	....	....	....	....	....	....	....	3	7	5	....	....	....	....	....	15
77.5	....	....	....	....	....	....	....	....	....	2	2	2	....	....	....	....	6
82.5	....	....	....	....	....	....	....	....	....	2	....	....	....	....	....	....	2
87.5	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....	1
92.5	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	1
97.5	....	....	....	....	....	....	....	....	....	2	....	....	....	....	....	....	2
Frequency	2	3	2	3	12	32	62	164	126	125	28	8	2	1	....	1	571

Correlation $= 0.504 \pm 0.021$.

TABLE XVI.—*Weight in decigrams of kernels per plant correlated with average weight in milligrams of kernels per plant. 1916*

Average weight of kernels per plant (mgm.).	Yield of kernels per plant (dgm.). 14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	Frequency.
1.5	3	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	4
4.5	....	....	2	2	1	3	2	2	1	2	2	1	....	....	....	....	18
7.5	....	....	....	....	1	1	3	4	2	3	4	4	7	4	3	1	37
10.5	....	1	1	....	1	2	5	8	20	19	18	2	2	2	3	....	84
13.5	....	....	....	....	....	2	9	12	8	11	22	28	10	2	3	....	107
16.5	....	....	1	....	2	....	2	12	30	46	16	11	18	6	4	1	149
19.5	....	....	....	....	1	....	....	2	5	27	49	35	10	....	4	....	133
22.5	....	....	....	....	....	....	....	1	6	8	19	35	26	2	1	1	99
25.5	....	....	....	....	....	....	....	1	3	8	8	11	9	7	2	....	49
28.5	....	....	....	....	....	....	....	2	1	1	3	2	....	2	1	....	12
31.5	....	....	....	....	....	....	....	....	....	....	....	2	2	....	....	....	4
34.5	....	....	....	....	....	....	....	....	....	....	1	1	....	....	....	....	2
Frequency	3	1	4	3	6	8	21	44	76	125	142	132	84	25	21	3	698

Correlation $= 0.370 \pm 0.022$.

TABLE XVII.—*Yield in decigrams of kernels per plant correlated with average weight in milligrams of kernels per plant. 1917*

Average weight of kernels per plant (mgm.)	Yield of kernels per plant (dgm.) 20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	Frequency
1.5	1	...	...	...	...	...	...	1														2
4.5	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	1
7.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	1
10.5	...	...	...	...	...	...	...	...	...	1	...	1	1	...	...	1	4	1	...	...	...	11
13.5	...	...	...	...	...	...	...	...	...	1	2	3	1	4	3	2	1	1	...	...	...	18
16.5	...	...	...	...	...	...	1	...	...	...	...	3	2	4	11	6	2	...	...	...	...	29
19.5	...	...	...	...	...	1	...	1	...	...	...	2	7	5	17	13	7	2	...	...	...	55
22.5	...	...	...	...	...	...	...	...	...	1	1	1	11	21	13	8	4	2	...	...	...	62
25.5	...	...	1	...	...	...	...	...	1	1	2	1	3	16	30	20	2	1	...	...	...	78
28.5	...	...	...	...	...	...	...	...	...	1	...	1	3	4	38	37	8	1	...	...	...	93
31.5	...	...	...	...	...	...	...	...	...	...	...	...	1	3	19	29	5	...	...	...	1	58
34.5	...	...	...	...	...	...	...	...	...	...	...	...	1	2	2	13	4	4	1	...	...	27
37.5	...	...	...	...	...	...	...	...	...	...	...	...	2	3	3	13	3	2	1	...	...	27
40.5	...	...	...	...	...	...	...	...	...	...	...	...	1	2	3	3	1	1	...	...	...	11
43.5	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	...		1	...	...	...	3
46.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	1
49.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	1
52.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	......
55.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	1
Frequency	1	...	1	...	...	1	1	2	1	5	5	12	34	65	141	145	44	18	2	...	1	479

Correlation=0.3064±.027.

TABLE XVIII.—*Average height in centimeters of culms per plant correlated with average weight in milligrams of kernels per plant. 1914*

Average weight of kernels per plant (mgm.)	Average height of culms per plant (cm) 5.25	6.75	8.25	9.75	11.25	12.75	14.25	15.75	17.25	18.75	20.25	21.75	23.25	24.75	26.25	Frequency
27.5	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	1
32.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	......
37.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	......
42.5	...	...	...	1	3	...	...	...	...	...	...	...	...	...	...	4
47.5	...	1	...	2	5	3	1	...	...	...	...	...	...	...	...	12
52.5	...	...	1	5	6	2	4	...	2	1	...	...	...	...	...	21
57.5	...	1	2	5	7	6	6	...	3	1	1	...	1	...	...	33
62.5	1	...	1	2	13	8	6	2	4	2	2	...	...	...	...	41
67.5	...	...	2	...	7	7	8	5	3	5	3	1	2	...	...	43
72.5	...	...	...	1	8	4	9	1	8	5	10	1	1	...	...	48
77.5	...	...	...	4	9	3	9	2	9	5	4	2	3	...	...	50
82.5	...	...	...	1	4	...	7	1	3	2	4	...	1	...	1	24
87.5	...	...	...	...	...	1	...	2	3	1	3	1	1	2	1	15
92.5	...	...	...	...	...	...	1	1	1	...	2	...	...	...	...	5
97.5	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	1
102.5	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	1
107.5	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	1
Frequency	1	2	6	21	63	34	51	15	37	22	29	6	9	2	2	300

Correlation=0.458±0.030.

TABLE XIX.—*Average height in centimeters of culms per plant correlated with average weight in milligrams of kernels per plant. 1915*

Average weight of kernels per plant (mgm.)	Average height of culms per plant (cm.)																Frequency
	8.75	11.25	13.75	16.25	18.75	21.25	23.75	26.25	28.75	31.25	33.75	36.25	38.75	41.25	43.75	46.25	
62.5						1			1		1						3
67.5								1	3								4
72.5		1			1		1	1	1			1					6
77.5	1					2	3	3	2	1	2						14
82.5						3	3	4	3	4	1						18
87.5	1		1		3	4	5	16	13	10	4	1					58
92.5				1		5	7	21	15	15	5	1					70
97.5				1	2	6	8	29	32	27	6	2		1		1	115
102.5		1	1		5	6	19	46	25	36	1	3	2				145
107.5				1	1	5	12	31	22	21	5						98
112.5		1					3	7	7	8	3						29
117.5								5	1	2							8
122.5							1			1							2
127.5									1								1
Frequency	2	3	2	3	12	32	62	164	126	125	28	8	2	1	....	1	571

Correlation=0.071±0.028.

TABLE XX.—*Average height in centimeters of culms per plant correlated with average weight in milligrams of kernels per plant. 1916*

Average weight of kernels per plant (mgm.)	Average height of culms per plant (cm)																Frequency
	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	
50												1					1
54				1							1						2
58													1				1
62			1														1
66	1			1		3	1										6
70	1				1	1	1	1									5
74		1	1		1	1	7	6	3	7	1		1				29
78			1	1	1	3	8	21	21	20	11	3	2				92
82			1		1		2	9	42	44	39	12	1				151
86					1		1	6	8	43	61	61	19	4	1		205
90					1		1		2	10	26	39	42	10	8	1	140
94	1							1		1	3	13	15	10	9	1	54
98												3	3	1	2	1	10
102															1		1
Frequency	3	1	4	3	6	8	21	44	76	125	142	132	84	25	21	3	698

Correlation=0.648±0.014.

TABLE XXI.—*Average height in centimeters of culms per plant correlated with average weight in milligrams of kernels per plant. 1917*

Average weight of kernels per plant (mgm.)	Average height of culms per plant (cm)																					Frequency
	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	
37.5	1																					1
42.5																						
47.5								1														1
52.5																						
57.5																						
62.5																						
67.5																1						1
72.5																						
77.5												1	1									2
82.5							1			1	1	1	2	1	2		1					10
87.5								1		1	1	4	10	19	15	9	3	2				65
92.5			1						1	1	2	4	16	24	58	38	10	3			1	159
97.5						1				1	1	2	5	14	55	71	20	5	2			177
102.5										1				7	11	26	9	6				60
107.5																	1	2				3
Frequency	1	...	1	...	...	1	1	2	1	5	5	12	34	65	141	145	44	18	2	...	1	479

Correlation=0.426±0.025.

YIELD OF KERNELS CORRELATED WITH OTHER PLANT CHARACTERS

The coefficients for yield of kernels per plant correlated with number of kernels per plant are 0.851±.0.010 in 1914, 0.881±0.006 in 1915, 0.952±0.002 in 1916, and 0.973±0.001 in 1917. In contrast with the coefficients when weight of seed was correlated with plant characters, the correlation is consistently high in each of the four years. With a fair uniformity in the average weight of kernels, high correlation between yield of kernels and number of kernels is to be expected.

Yield of kernels correlated with average weight of kernels gave coefficients of 0.550±0.027 in 1914, 0.504±0.021 in 1915, 0.370±20.02 in 1916, and 0.306±0.027 in 1917. This order is the opposite of the general tendency for the coefficients in this group to be lower in the first two than in the last two years. The correlation between the two characters is substantial and fairly consistent. This indicates that the higher yielding plants have a tendency to produce kernels of greater average weight.

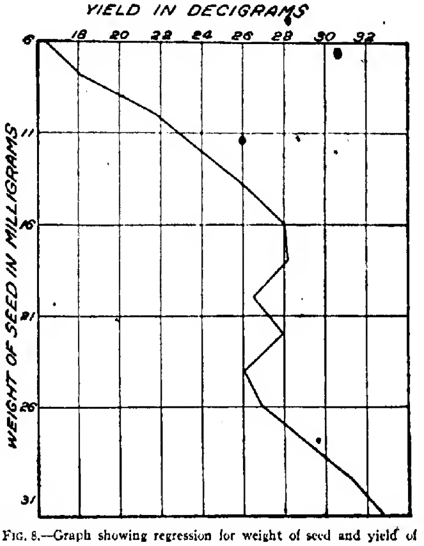

FIG. 8.—Graph showing regression for weight of seed and yield of kernels per wheat plant in 1917.

The coefficients for yield of kernels correlated with the number of culms are 0.500±0.029 in 1914, 0.669±0.015 in 1915, 0.818±0.008 in 1916, and 0.824±0.009 in 1917. The correlation between the two characters is relatively high, but not as consistent as that between yield of kernels and number of kernels. Plants with the greater number of culms are usually the higher yielders.

For yield of kernels correlated with average height of culms the coefficients are 0.303±0.025 in 1915, 0.384±0.033 in 1914, 0.452±0.024 in 1917, and 0.478±0.019 in 1916. This is a substantial and fairly consistent correlation. For yield of kernels and average length of spikes, the coefficients are very similar to those between yield of kernels and average height of culms. There is a distinct tendency for the plants

producing the higher yields of grain to have the greater average height of culms and greater average length of spikes. Stated in another way, the plants having the greater average height of culms and average length of spikes have a tendency toward being the highest yielders.

The coefficients for yield of kernels correlated with total length of spikes per plant are 0.636±0.023 in 1914, 0.808±0.009 in 1915, 0.910±0.004 in 1916, and 0.911±0.005 in 1917. Correlation between these two characters is high and relatively consistent approaching that between yield of kernels and number of kernels. Stated directly, the plants with the greatest total length of spikes were generally the highest yielders.

The results for yield of kernels correlated with the several characters may be summarized as follows: An increased yield of kernels is very closely accompanied by an increase in number of kernels, number of culms, and total length of spikes, and somewhat less closely accompanied by an increase in average weight of kernels per plant, average height of culms, and average length of spikes.

NUMBER OF CULMS CORRELATED WITH OTHER PLANT CHARACTERS

For number of culms correlated with average length of spikes per plant, the coefficients are 0.061±0.038 in 1914, 0.024±0.028 in 1915, 0.039±0.025 in 1916, and 0.236±0.029 in 1917. In the first three years there is practically none, and in the last year a low correlation. The conclusion is that these two characters move practically independent of each other.

The coefficients for number of culms correlated with total length of spikes per plant are 0.872±0.009, 0.839±0.008, 0.958±0.002, and 0.946±0.003, respectively, for the 4-year period. The correlation between the two characters is somewhat more close and consistent than that between yield of kernels and total length of spikes. An increase in number of culms is followed by an increase in total length of spikes per plant, but not by greater average length of spikes.

AVERAGE WEIGHT OF KERNELS CORRELATED WITH OTHER PLANT CHARACTERS

The coefficients for average weight of kernels as correlated with number of kernels per plant are 0.137±0.038, 0.192±0.027, 0.160±0.024, and 0.160±0.030, respectively, for the four years. The coefficients are uniformly low but positive in each instance with the lowest 3.6 times its probable error. To a limited extent, an increase in number of kernels is accompanied by a greater average weight of the kernels.

Average weight of kernels correlated with number of culms per plant gave coefficients of −0.071±0.038 in 1914, 0.137±0.027 in 1915, −0.054±0.025 in 1916, and −0.009±0.030 in 1917. The low coefficients as judged by their probable errors and the variation from year shows slight or no correlation between these characters.

The coefficients for average weight of kernels correlated with average length of spikes are 0.153±0.038, 0.120±0.027, 0.552±0.017, and 0.411±0.025, respectively, for the four years. The relatively low correlation in the first two and the substantial correlation in the last two years indicates that under the conditions of environment which prevailed in 1916 and 1917 there is a strong tendency for the two characters to move together; and that under extreme environmental conditions such as prevailed in 1914 and 1915 the relation is considerably reduced.

For average weight of kernels correlated with total length of spikes, the coefficients range from 0.001±0.038 in 1914 to 0.159±0.027 in 1915. There is no correlation in 1914, and for the three other years the relation is low. Therefore the conclusion must be that the two characters move practically independent of each other.

When average weight of kernels is correlated with number of kernels, number of culms, average length of spikes, and total length of spikes, no consistently high relationship is found. Subject to radical change by environment, there is a moderate relation with average length of spikes. With number of kernels the correlation is rather low but consistent. Average weight of kernels is practically independent of total length of spikes.

AVERAGE HEIGHT OF CULMS CORRELATED WITH OTHER PLANT CHARACTERS

The coefficients for average length of culms correlated with number of kernels per plant are 0.257±0.036, 0.339±0.025, 0.364±0.022, and 0.431±0.025, respectively, for the four years. This is a substantial and fairly consistent relation very similar to that found between yield of kernels and average height of culms. There is a tendency for an increase or a decrease in average height of culms to result in the production of a larger or smaller number of kernels per plant.

When average height of culms is correlated with average weight of kernels, the coefficients are 0.458±0.030 in 1914, 0.071±0.028 in 1915, 0.648±0.014 in 1916, and 0.426±0.025 in 1917. With the exception of the very low correlation in 1915 due to extremely favorable environmental conditions, the relation is substantial. The indications are that under ordinary conditions there is a tendency for increase or decrease in average height of culms to be accompanied by a raising or lowering of average kernel weight.

For average height of culms correlated with number of culms per plant the coefficients are −0.195±0.037 in 1914, −0.092±0.028 in 1915, 0.046±0.025 in 1916, and 0.205±0.029 in 1917. The correlation varies considerably from year to year and is low in each instance. Therefore the conclusion may be drawn that the slight tendency for the two characters to vary together is highly modified by the influences of environment.

The coefficients for average height of culms correlated with average length of spikes per plant are 0.315 ± 0.035 in 1914, 0.419 ± 0.023 in 1915, 0.775 ± 0.010 in 1916, and 0.668 ± 0.017 in 1917.

Similar to the correlation between yield of kernels and average length of spikes, the relation of these two characters has a tendency to be high, but is strongly modified by environmental conditions.

When average height of culms is correlated with total length of spikes per plant, the coefficients are 0.036 ± 0.038, 0.260 ± 0.026, 0.235 ± 0.024, and 0.351 ± 0.027. This is a variation from no correlation to a fairly substantial one. The influence of environment may entirely overcome the tendency of the two characters to move together.

Considering as a whole the relation of average height of culms to other plant characters, there is a tendency for an increase or decrease in average height of culms to be accompanied by an increase or decrease in number of kernels and average length of spikes. Between average height of culms and average weight of kernels there is a substantial correlation and between average height of culms and total length of spikes there is a moderate correlation three years out of four. The correlation between average height of culms and number of culms is always low.

CORRELATION OF HEIGHT OF PLANTS AT DIFFERENT STAGES OF DEVELOPMENT

When height at appearance of second leaf is correlated with height of the same plants at six weeks from seeding, the coefficients are 0.406 ± 0.038 in 1914, 0.467 ± 0.022 in 1915, 0.470 ± 0.019 in 1916, and 0.466 ± 0.024 in 1917. The correlation between the two characters is substantial and consistent.

For height of plants at appearance of second leaf correlated with height of tallest culm at maturity, the coefficients are 0.380 ± 0.033 in 1914, 0.270 ± 0.026 in 1915, 0.272 ± 0.023 in 1916, and 0.211 ± 0.029 in 1917. This is a medium correlation modified considerably by environmental influences.

The coefficients for height at six weeks correlated with height of the tallest culms of the same plants at maturity are 0.399 ± 0.038, 0.236 ± 0.026, 0.523 ± 0.018, and 0.314 ± 0.027. The correlation between the two characters varies from rather low to moderately high depending upon the environment.

Considering as a whole the correlations between height of plants at different stages of development, there is a distinct tendency for plants of varying heights at second leaf to maintain the same relative heights at six weeks, but there is a lesser tendency for this relation to be maintained at maturity. Some of the shorter plants at second leaf approach closely or equal in height the taller ones at maturity. There is a tendency, considerably modified by environment, for differences in heignt of plants at six weeks to be maintained in the tallest culm at maturity.

Considering the interrelation of plant characters as a whole, there is a range from practically none to a high correlation. Correlation is modified by environment, the degree of modification due to this cause varying with the characters considered.

An increased yield of kernels is very closely accompanied by an increase in number of kernels, number of culms, and total length of spikes; and somewhat less closely accompanied by increase in average weight of kernels per plant, average height of culms, and average length of spikes.

A larger number of culms per plant is accompanied by a greater total length of spikes but not by a greater average length of spikes.

Average weight of kernels is substantially and fairly consistently correlated with yield of kernels; and, subject to radical change due to environment, moderately correlated with average length of spikes. With number of kernels, the correlation is rather low but always consistent. Average weight of kernels is practically independent of average length of spikes.

There is a distinct tendency for greater average height of culms to be accompanied by a greater average length of spikes, number of kernels, and a higher yield of kernels. Average height of culms is substantially correlated with average weight of kernels and moderately correlated with total length of spikes in three years out of four. The correlation between average height of culms and number of culms is always low.

There is a distinct tendency for plants of varying heights at second leaf to maintain the same relative heights at six weeks; but there is a lesser tendency for this relation to be maintained at maturity.

GENERAL DISCUSSION

During early growth in 1914 and 1915, the means for height of the plants are greater than those in 1916 and 1917, owing to the somewhat more productive soil on which the plants were grown, to the more favorable weather conditions, and to a higher average weight of seed planted. In 1915 the favorable growing conditions continued throughout the season, and the mean for each plant character at maturity, except average weight of seed, is the highest in the 4-year period. In 1914, during July, drouth followed by an epidemic of black-stemrust lowered materially the means for all plant characters at maturity.

For each of the characters studied, except yield of kernels, the variability as indicated by the standard deviations, is as high as or higher in 1914 and 1915 than in 1916 and 1917. The generally higher variability in the former two as compared with that in the latter two years is accompanied by generally lower correlation coefficients (1) when weight of seed sown is correlated with resultant plant characters and (2) when yield of kernels is correlated with other plant characters.

When weight of seed sown is correlated with plant characters at maturity, it is noticeable that in 1915 there are four coefficients with the minus sign and that there is a tendency for the coefficients to be lower than in 1914.

In contrast with the low and varying relation in 1914 and 1915 is the generally moderate and consistent correlation between weight of seed sown and plant characters in 1916 and 1917 when the plants were grown on the poorer soil and from somewhat lower mean weight of seed.

From this study conclusive evidence is given that for the conditions under which the work was done, environment reduced radically or obliterated entirely the correlation between weight of seed sown and plant characters among which is yield.

This information answers, in part at least, the questions raised in the introduction to this article regarding the rôle of weather and soil in comparisons of heavy and light seed for planting.

If these results were applicable to the wheat crop in general during the 4-year period, it is clear that on soils of moderately high productivity with favorable weather conditions heavy kernels as compared with light kernels used for planting may be expected to give very moderate or no increase in yield.

In the study of the interrelation of plant characters a substantial and fairly consistent correlation was found between yield of kernels and average weight of kernels, average height of culms, and a somewhat higher correlation with number of culms. Between average height of culms and average weight of kernels there is a moderately high correlation each year, except in 1915, when the coefficient is very low.

If these relations held for the wheat crop during the 4-year period, separating from the crop each year seed of higher average weight would be selecting seed from plants which had a decided tendency toward higher yield, and, with the exception of the year 1915, from plants which were taller and at the same time higher yielding. In 1915 there was practically no relation between average weight of kernels and average height of culms, and separating the larger seeds from this crop would be selecting seed from both high and low yielding plants.

The tendency of the tallest plants and the plants having the greatest number of culms to be the highest yielders is a valuable index in making individual plant selections from mixed populations.

SUMMARY OF CONCLUSIONS

Subject to the environmental conditions under which the work was done, the following conclusions may be drawn:

(1) The magnitude of the means for any of the characters studied varied in response to environmental conditions. Lower yields of straw resulted from a reduction in number, total length, or average length of culms per plant; and lower yields of grain from a reduction in the

number of kernels. When the kernels developed normally, lower yield was accompanied by a higher average weight per kernel.

(2) In general, a reduction in the magnitude of the means is accompanied by less variability. A number of exceptions to this general tendency occurred.

(3) Correlation between weight of seed sown and resultant plant characters at maturity is not high in any instance and may be so modified by environmental conditions that the relation may be slight or obliterated entirely.

(4) Correlation between plant characters is modified by environment, the degree of modification from this cause varying with the characters considered.

(5) An increased yield of kernels is very closely accompanied by an increase in number of kernels, number of culms, and total length of spikes; and somewhat less closely accompanied by an increase in average weight of kernels per plant, average height of culms, and average length of spikes.

(6) A larger number of culms per plant is accompanied by a greater total length of spikes but not by a greater average length of spikes.

(7) Average weight of kernels is substantially and fairly consistently correlated with yield of kernels, and, subject to radical change due to environment, moderately correlated with average length of spikes. With number of kernels the correlation is rather low but always consistent. Average weight of kernels is practically independent of average length of spikes.

(8) There is a distinct tendency for greater average height of culms to be accompanied by greater average length of spikes, number of kernels, and higher yield of kernels. Average length of spikes is moderately correlated with average weight of kernels three years out of four. The correlation between average height of culms and number of culms is always low.

(9) There is a distinct tendency for plants of varying height at second leaf to maintain the same relative heights at six weeks, but there is a lesser tendency for this relation to be maintained at maturity.

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OBTAINING BEET LEAFHOPPERS NONVIRULENT AS TO CURLY-TOP

[PRELIMINARY PAPER]

By C. F. STAHL, *Scientific Assistant, Truck-Crop Insect Investigations, Bureau of Entomology*, and EUBANKS CARSNER, *Assistant Pathologist, Sugar-Plant Investigations, Bureau of Plant Industry, United States Department of Agriculture*

The beet leafhopper (*Eutettix tenella* Baker) is the only known agent capable of transmitting the disease of the sugar beet (*Beta vulgaris*) known as curly-top. The fact that under some conditions, when collected from wild vegetation, the insects of this species failed to occasion the beet disease until they had fed on diseased plants was first shown by Boncquet and Hartung [1] and later confirmed by Smith and Boncquet.[2] Experiments which had been started previously by Stahl to determine whether or not a leafhopper which has never fed on beets affected with curly-top will produce the disease proved the point, which was inferred from the discovery mentioned above, that it will not. Further tests made by the present writers to verify the earlier results have led to the development of the method, here to be described, of obtaining nonvirulent leafhoppers with certainty and relative ease.

The manner in which the egg of the leafhopper hatches makes it possible to remove the young nymph from the diseased to a healthy plant before it has had an opportunity to feed. The eggs are laid mainly in the petioles and midribs of the leaves. In the process of hatching the nymph forces its way, anterior end first, from the egg case and through the slit of the ovipositor. This is accomplished by an undulating movement of the body. Emergence from the egg membrane is practically complete, and the body of the insect reaches a position more or less perpendicular to the plant surface before the appendages begin to unfold. As the appendages unfold the contortions of the body become more vigorous until the young nymph gains a foothold on the substratum. It is then able to free itself entirely from the egg membrane. The process is completed after from 5 to 16 minutes. During the latter part of the operation, when the appendages are unfolding, the opportunity is afforded of lifting the nymph off and transferring it to a healthy plant. Its transfer can be best effected by means of a small camel's-hair brush.

The first experiment, by Stahl, was begun on April 19, 1915. On that day three lots of nymphs, numbering 7, 9, and 15 individuals, respec-

[1] BONCQUET, P. A., and HARTUNG, WM. J., THE COMPARATIVE EFFECT UPON SUGAR BEETS OF EUTETTIX TENELLA BAKER FROM WILD PLANTS AND FROM CURLY-TOP BEETS. *In* Phytopathology, v. 5, no. 6, p. 348-349. 1916.

[2] SMITH, RALPH E., and BONCQUET, P. A. CONNECTION OF A BACTERIAL ORGANISM WITH CURLY LEAF OF SUGAR BEET. *In* Phytopathology, v. 5, no. 6, p. 335-341. 1915.

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tively, were transferred as they hatched to three healthy beet plants in separate cages. The insects were left on the plants until after they had become adults. All three plants remained healthy. On July 3 the insects of two of the lots were caged on two separate plants affected with curly-top. After 17 days they were again caged on two healthy plants. Both of these plants developed the disease.

A similar test was begun on May 17, 1915. Three lots of approximately 15 nymphs each were placed on healthy beets as before. At the same time two similar lots were transferred to diseased beets as controls. After the insects of the latter two lots were about half grown they were shifted to two healthy plants. These plants became diseased, while the three plants on which the first three lots were placed and kept remained healthy.

Recently some work was performed jointly by the writers to verify the earlier results and to secure a supply of nonvirulent leafhoppers for laboratory experiments. Three lots of nymphs, numbering approximately 50, 100, and 200, respectively, were lifted off in the manner described and placed on three healthy beet plants. The three lots were kept separate, and about 60 per cent of each grew to maturity on the original plants or on fresh healthy plants which were substituted as needed. In no case has a plant on which these insects were caged developed curly-top. During the same time the disease developed in other plants with which virulent insects had been caged under similar conditions. Single leafhoppers from each of the three lots have been caged on healthy plants without apparent effect, while at the same time virulent insects, caged individually on healthy plants, have quickly induced the disease. After having been caged on diseased plants, however, the nonvirulent insects have become virulent.

These results show conclusively that uninfected insects placed on healthy beet plants will not produce curly-top. They are of further interest because the possibility of obtaining a supply of leafhoppers known positively to be nonvirulent opens up several promising lines of attacking the disease problem. For instance, nonvirulent leafhoppers may be used to determine whether or not other plants than beets harbor the virus of curly-top. The peculiar disease of the common mallow (*Malva parviflora* L.) was thus shown by Boncquet and Stahl[1] to be caused by the same virus which causes the beet disease.

[1] BONCQUET, P. A., and STAHL, C. F. WILD VEGETATION AS A SOURCE OF CURLY-TOP INFECTION OF SUGAR BEETS. *In* Jour. Econ. Ent., v. 10, no. 4, p. 392–397, pl. 17–18. 1917.